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PILOT-SCALE INVESTIGATION OF CLOSED-LOOP FLY ASH SLUICING

VOL. 2 - APPENDICES

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ABSTRACT

This project was a pilot-scale demonstration of the technical feasibility of closed-loop operation of fly ash sluicing systems. Chemical species leached from the ash increase the dissolved solids concentration of recycled sluice water to a point where scaling of equipment may occur. Tests were conducted at two power plants using a 50 gpm pilot unit to demonstrate the feasibility of closed-loop operation, both with and without sluice water treatment. An ash sluice computer process model was developed for prediction of chemistry and process conditions in full-scale systems.

Closed-loop operation of fly ash sluicing systems handling highly reactive alkaline ashes cannot be achieved without treatment of sluice water to control scale formation. Acid addition for pH adjustment was effective in controlling calcium carbonate scale formation in the sluice water return line; however, use of sulfuric acid increased the potential for gypsum scale formation. Gypsum was ultimately the limiting species which prevented reliable closed-loop operation at the plants tested. Increased ash/water contact time in a reaction tank was not adequate to control the potential for gypsum scale formation at the residence times tested.

The ash sluice computer process model was proven to be accurate in predicting the chemical composition and potential for scale formation in the pilot unit. This model is an effective tool for the resolution of ash sluicing system operating problems or to support the design of systems in new plants.

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APPENDIX A

EQUILIBRIUM MODEL REACTIONS

TABLE A-1

CHEMICAL EQUILIBRIUM MODEL REACTIONS AND RELATIONS

A: Gas-Liquid Equilibria

Reaction	Equilibrium Relation
$CO_2(g) + H_2O(\ell) \rightleftarrows H_2CO_3(\ell)$	$P(CO_2)\ \gamma(H_2O)\ K_p(CO_2) = a(H_2CO_3)$
$HNO_3(g) \rightleftarrows HNO_3(\ell)$	$P(HNO_3)\ K_p(HNO_3) = a(HNO_3)$
$NH_3(g) \rightleftarrows NH_3(\ell)$	$P(NH_3)\ K_p(NH_3) = a(NH_3)$

B: Liquid-Liquid Equilibria

Reaction	Equilibrium Relation
$H_2O \rightleftarrows H^+ + OH^-$	$K_1\ \gamma(H_2O) = a(H^+)\ a(OH^-)$
$H_2CO_3 \rightleftarrows H^+ + HCO_3^-$	$K_2\ a(H_2CO_3) = a(H^+)\ a(HCO_3^-)$
$HCO_3^- \rightleftarrows H^+ + CO_3^{=}$	$K_3\ a(HCO_3^-) = a(H^+)\ a(CO_3^{=})$
$HNO_3 \rightleftarrows H^+ + NO_3^-$	$K_4\ a(HNO_3) = a(H^+)\ a(NO_3^-)$
$H_4SiO_4 \rightleftarrows H^+ + H_3SiO_4^-$	$K_5\ a(H_4SiO_4) = a(H^+)\ a(H_3SiO_4^-)$
$H_3SiO_4^- \rightleftarrows H^+ + H_2SiO_4^{=}$	$K_6\ a(H_3SiO_4^-) = a(H^+)\ a(H_2SiO_4^{=})$
$HSO_4^- \rightleftarrows H^+ + SO_4^{=}$	$K_7\ a(HSO_4^-) = a(H^+)\ a(SO_4^{=})$
$H_3PO_4 \rightleftarrows H^+ + H_2PO_4^-$	$K_8\ a(H_3PO_4) = a(H^+)\ a(H_2PO_4^-)$
$H_2PO_4^- \rightleftarrows H^+ + HPO_4^{=}$	$K_9\ a(H_2PO_4^-) = a(H^+)\ a(HPO_4^{=})$
$HPO_4^{=} \rightleftarrows H^+ + PO_4^{\equiv}$	$K_{10}\ a(HPO_4^{=}) = a(H^+)\ a(PO_4^{\equiv})$
$NH_4^+ \rightleftarrows H^+ + NH_3$	$K_{11}\ a(NH_4^+) = a(H^+)\ a(NH_3)$
$CaOH^+ \rightleftarrows Ca^{++} + OH^-$	$K_{12}\ a(CaOH^+) = a(Ca^{++})\ a(OH^-)$
$CaCO_3 \rightleftarrows Ca^{++} + CO_3^{=}$	$K_{13}\ a(CaCO_3) = a(Ca^{++})\ a(CO_3^{=})$
$CaHCO_3^+ \rightleftarrows Ca^{++} + HCO_3^-$	$K_{14}\ a(CaHCO_3^+) = a(Ca^{++})\ a(HCO_3^-)$
$CaNO_3^+ \rightleftarrows Ca^{++} + NO_3^-$	$K_{15}\ a(CaNO_3^+) = a(Ca^{++})\ a(NO_3^-)$
$CaSO_4 \rightleftarrows Ca^{++} + SO_4^{=}$	$K_{16}\ a(CaSO_4) = a(Ca^{++})\ a(SO_4^{=})$
$CaH_2PO_4^+ \rightleftarrows H^+ + CaHPO_4$	$K_{17}\ a(CaH_2PO_4^+) = a(H^+)\ a(CaHPO_4)$
$CaHPO_4 \rightleftarrows H^+ + CaPO_4^-$	$K_{18}\ a(CaHPO_4) = a(H^+)\ a(CaPO_4^-)$

continued...

TABLE A-1, Continued.

B: Liquid-Liquid Equilibria
(continued)

Reaction	Equilibrium Relation
$CaNO_3^+ \rightleftarrows Ca^{++} + NO_3^-$	$K_{15}\ a(CaNO_3^+) = a(Ca^{++})\ a(NO_3^-)$
$CaSO_4 \rightleftarrows Ca^{++} + SO_4^=$	$K_{16}\ a(CaSO_4) = a(Ca^{++})\ a(SO_4^=)$
$CaH_2PO_4^+ \rightleftarrows H^+ + CaHPO_4$	$K_{17}\ a(CaH_2PO_4^+) = a(H^+)\ a(CaHPO_4)$
$CaHPO_4 \rightleftarrows H^+ + CaPO_4^-$	$K_{18}\ a(CaHPO_4) = a(H^+)\ a(CaPO_4^-)$
$CaPO_4^- \rightleftarrows Ca^{++} + PO_4$	$K_{19}\ a(CaPO_4^-) = a(Ca^{++})\ a(PO_4)$
$MgOH^+ \rightleftarrows Mg^{++} + OH^-$	$K_{20}\ a(MgOH^+) = a(Mg^{++})\ a(OH^-)$
$MgHCO_3^+ \rightleftarrows H^+ + MgCO_3$	$K_{21}\ a(MgHCO_3^+) = a(H^+)\ a(MgCO_3)$
$MgCO_3 \rightleftarrows Mg^{++} + CO_3^=$	$K_{22}\ a(MgCO_3) = a(Mg^{++})\ a(CO_3^=)$
$MgSO_4 \rightleftarrows Mg^{++} + SO_4^=$	$K_{23}\ a(MgSO_4) = a(Mg^{++})\ a(SO_4^=)$
$MgHPO_4 \rightleftarrows H^+ + Mg^{++} + PO_4^{\equiv}$	$K_{24}\ a(MgHPO_4) = a(H^+)\ a(Mg^{++})\ a(PO_4^{\equiv})$
$NaOH \rightleftarrows Na^+ + OH^-$	$K_{25}\ a(NaOH) = a(Na^+)\ a(OH^-)$
$NaHCO_3 \rightleftarrows H^+ + NaCO_3^-$	$K_{26}\ a(NaHCO_3) = a(H^+)\ a(NaCO_3^-)$
$NaCO_3^- \rightleftarrows Na^+ + CO_3^=$	$K_{27}\ a(NaCO_3^-) = a(Na^+)\ a(CO_3^=)$
$NaNO_3 \rightleftarrows Na^+ + NO_3^-$	$K_{28}\ a(NaNO_3) = a(Na^+)\ a(NO_3^-)$
$NaSO_4^- \rightleftarrows Na^+ + SO_4^=$	$K_{29}\ a(NaSO_4^-) = a(Na^+)\ a(SO_4^=)$
$NH_4HCO_3 \rightleftarrows NH_4^+ + HCO_3^-$	$K_{30}\ a(NH_4HCO_3) = a(NH_4^+)\ a(HCO_3^-)$
$NH_4CO_3^- \rightleftarrows NH_4^+ + CO_3^=$	$K_{31}\ a(NH_4CO_3^-) = a(NH_4^+)\ a(CO_3^=)$
$NH_4HSO_4 \rightleftarrows NH_4^+ + HSO_4^-$	$K_{32}\ a(NH_4HSO_4) = a(NH_4^+)\ a(HSO_4^-)$
$NH_4SO_4^- \rightleftarrows NH_4^+ + SO_4^=$	$K_{33}\ a(NH_4SO_4^-) = a(NH_4^+)\ a(SO_4^=)$
$KSO_4^- \rightleftarrows K^+ + SO_4^=$	$K_{34}\ a(KSO_4^-) = a(K^+)\ a(SO_4^=)$

continued...

TABLE A-1, Continued.

C: Solid-Liquid Equilibria

Reaction	Equilibrium Relation
$Ca(OH)_2(s) \rightleftarrows Ca^{++} + 2OH^-$	$K_{sp}\ (Ca(OH)_2) \geq a(Ca^{++})\ a(OH^-)^2$
$CaCO_3(s) \rightleftarrows Ca^{++} + CO_3^=$	$K_{sp}\ (CaCO_3) \geq a(Ca^{++})\ a(CO_3^=)$
$Ca_3(PO_4)_2(s) \rightleftarrows 3Ca^{++} + 2PO_4^{\equiv}$	$K_{sp}\ (Ca_3(PO_4)_2) \geq a(Ca^{++})^3\ a(PO_4^{\equiv})^2$
$CaSO_4(s) \rightleftarrows Ca^{++} + SO_4^=$	$K_{sp}\ (CaSO_4) \geq a(Ca^{++})\ a(SO_4^=)$
$CaSO_4 \cdot 2H_2O(s) \rightleftarrows Ca^{++} + SO_4^= + 2H_2O(\ell)$	$K_{sp}\ (CaSO_4 \cdot 2H_2O) \geq a(Ca^{++})\ a(SO_4^=)\ \gamma(H_2O)^2$
$Mg(OH)_2(s) \rightleftarrows Mg^{++} + 2OH^-$	$K_{sp}\ (Mg(OH)_2) \geq a(Mg^{++})\ a(OH^-)^2$
$MgCO_3 \cdot 5H_2O(s) \rightleftarrows Mg^{++} + CO_3^= + 5H_2O(\ell)$	$K_{sp}\ (MgCO_3 \cdot 5H_2O) \geq a(Mg^{++})\ a(CO_3^=)\ \gamma(H_2O)^5$
$Mg_2Si_3O_8(H_2O)_3(s) + 5H_2O \rightleftarrows 3H_3SiO_4^- + 3H^+ + 2Mg^{++} + 4OH^-$	$K_{sp}\ (Mg_2Si_3O_8(H_2O)_3)\ \gamma(H_2O)^5 \geq a(H_3SiO_4^-)^3\ a(H^+)^3\ a(Mg^{++})^2\ (OH^-)^4$
$CaH_2SiO_4(s) \rightleftarrows Ca^{++} + H_2SiO_4^=$	$K_{sp}\ (CaH_2SiO_4) \geq a(Ca^{++})\ a(H_2SiO_4^=)$
$SiO_2(s) + 2H_2O \rightleftarrows H_3SiO_4^- + H^+$	$K_{sp}\ (SiO_2)\ \gamma(H_2O)^2 \geq a(H_3SiO_4^-)\ a(H^+)$
$CaHPO_4(s) \rightleftarrows Ca^{++} + HPO_4^=$	$K_{sp}\ (CaHPO_4) \geq a(Ca^{++})\ a(HPO_4^=)$

APPENDIX B

ASH SLUICE MODEL EXAMPLE CASES

```
EXAMPLE CASE 1: NO TREATMENT, NO CO2 TRANSFER, NO SOLIDS IN POND
1111111
01 120.   .00481    .00001    .00003    .00002              .00302    .99103
   416.7
02 62.    44.1      13.       10.                 0.8       1.0       145.0
          38.1                                    8.0       3.0
06 3.0    50.0      5.0       10.0      75.0                1.0
07 40.    9.0
99


EXAMPLE CASE 2: ACID ADDITION (PH), NO CO2 TRANS., NO SOLIDS
2131111
01 120.   .00481    .00001    .00003    .00002              .00302    .99103
   416.7
02 62.    44.1      13.       10.                 0.8       1.0       145.0
          38.1                                    8.0       3.0
03
    0.
                    50.       2.0
06 3.0    50.0      5.0       10.0      75.0                1.0
07 40.    9.0       7.5
99
```

```
EXAMPLE CASE 3: REACTION TANK--RATE CONT. PRECIP, NO CO2 TRANS., NO SOLIDS
4111111
01 120.     .00481     .00001     .00003     .00002                .00302     .99103
    416.7
02 62.      44.1       13.        10.                   0.8        1.0        145.0
            38.1                                        8.0        3.0
06 3.0      50.0       5.0        10.0       75.0                  1.0
07 40.      9.0
14 1.0      100.
99

EXAMPLE CASE 4: SIDESTREAM SOFTENING--RATE SFT, NO CO2 TRANS., NO SOLIDS
3132111
01 120.     .00481     .00001     .00003     .00002                .00302     .99103
    416.7
02 62.      44.1       13.        10.                   0.8        1.0        145.0
            38.1                                        8.0        3.0
04          1.0                                         1.0
    0.
                       15.
06 3.0      50.0       5.0        10.0       75.0                  1.0
07 40.      9.0                   250.0
10 80.      60.        10.                   8.                               1.
    1.                 40.
99
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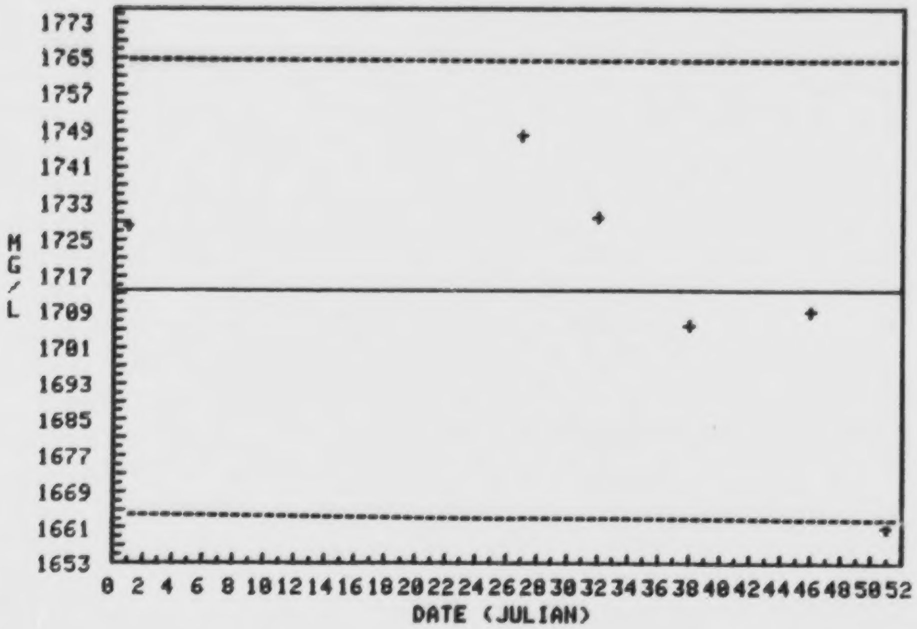
APPENDIX C

QUALITY CONTROL CHARTS

SULFATE: LOW CONCENTRATION



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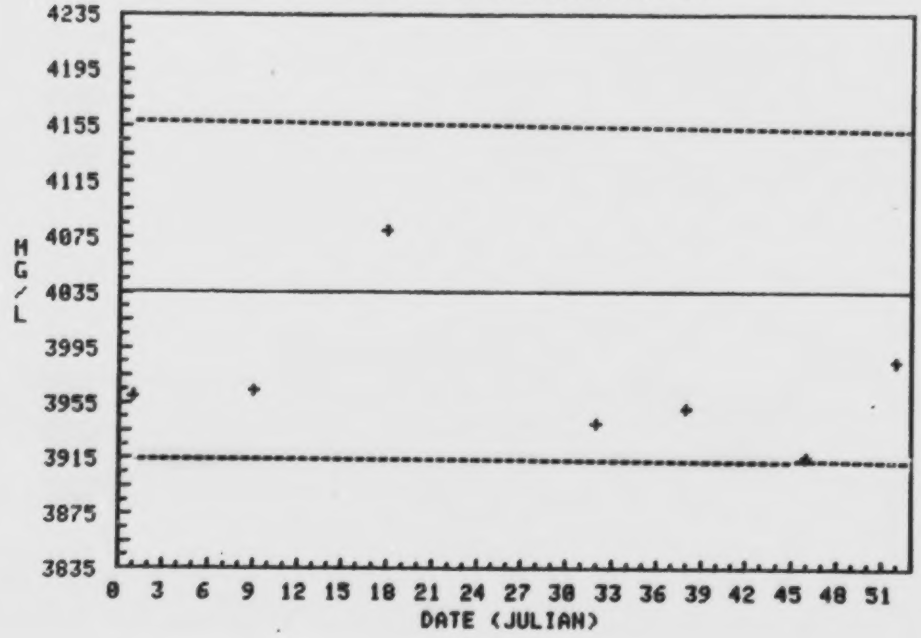
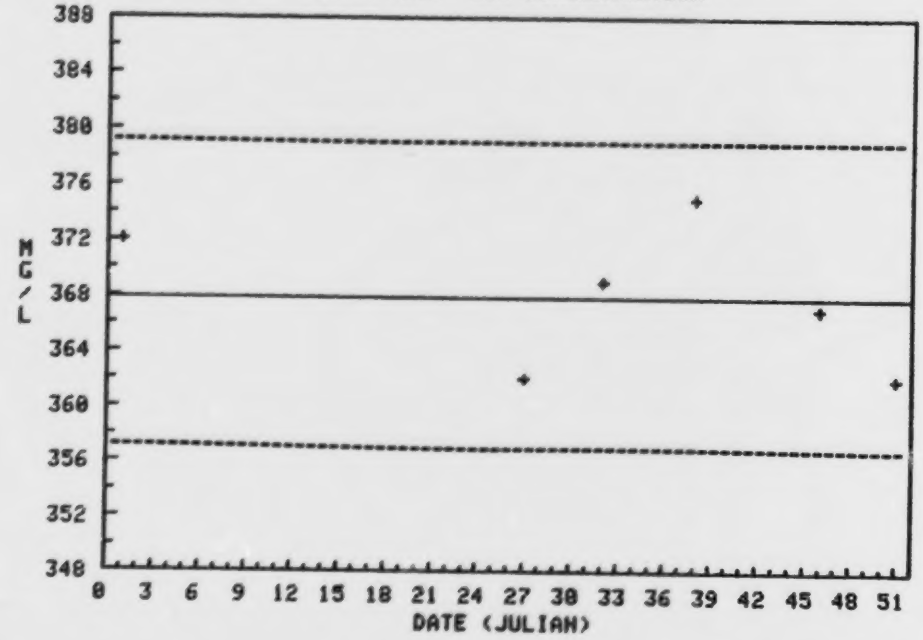
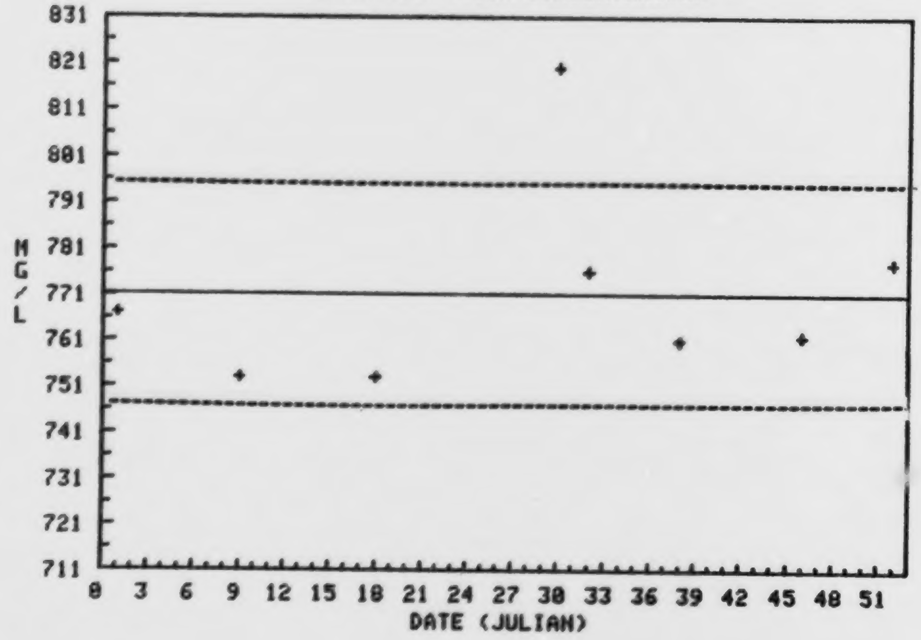
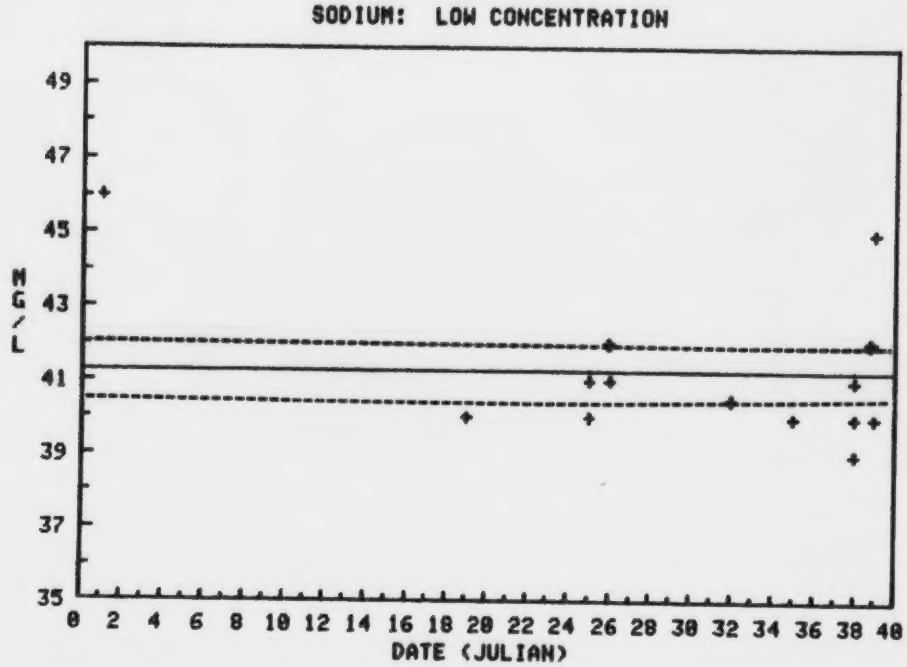


CHLORIDE: LOW CONCENTRATION



CHLORIDE: HIGH CONCENTRATION

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47
45
43
41
39
37
35
MG/L
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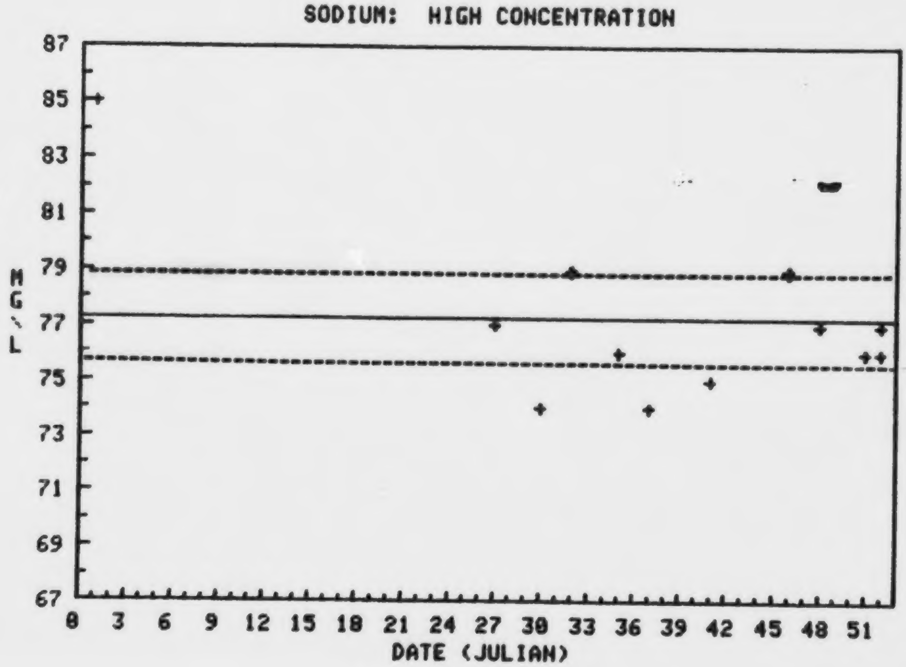
DATE (JULIAN)


SODIUM: HIGH CONCENTRATION
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85
83
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79
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73
71
69
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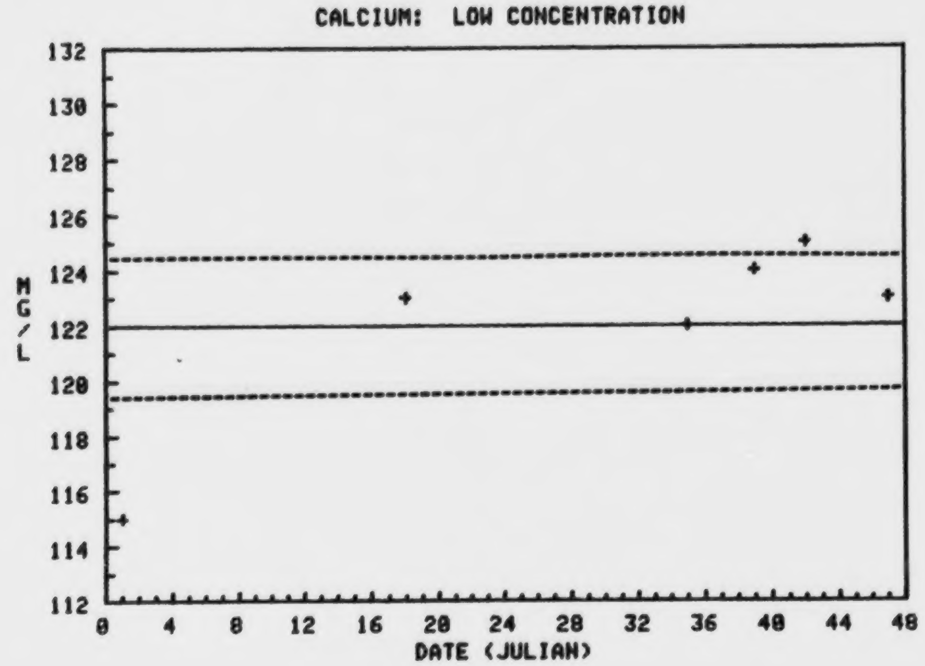
MG\L
0 3 6 9 12 15 18 21 24 27 30 33 36 39 42 45 48 51
DATE (JULIAN)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124
122
120
118
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MG/L
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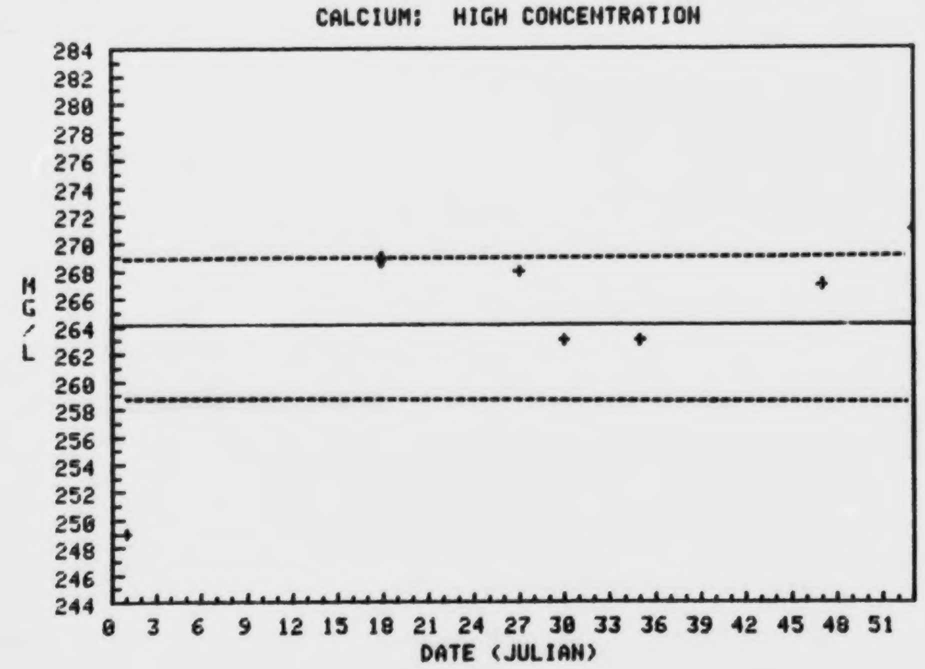
DATE (JULIAN)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282
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274
272
270
268
266
264
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256
254
252
250
248
246
244
MG/L
0
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18
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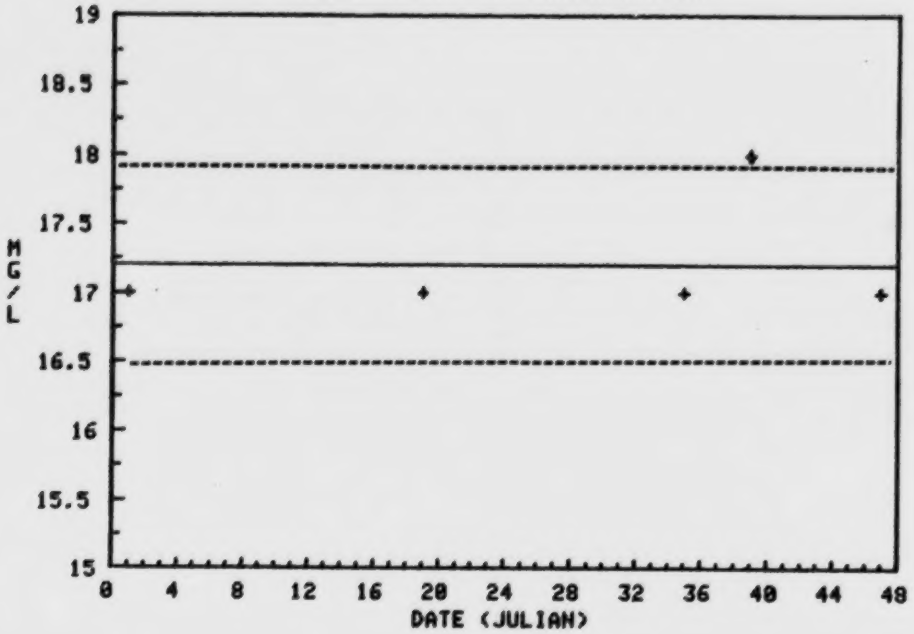
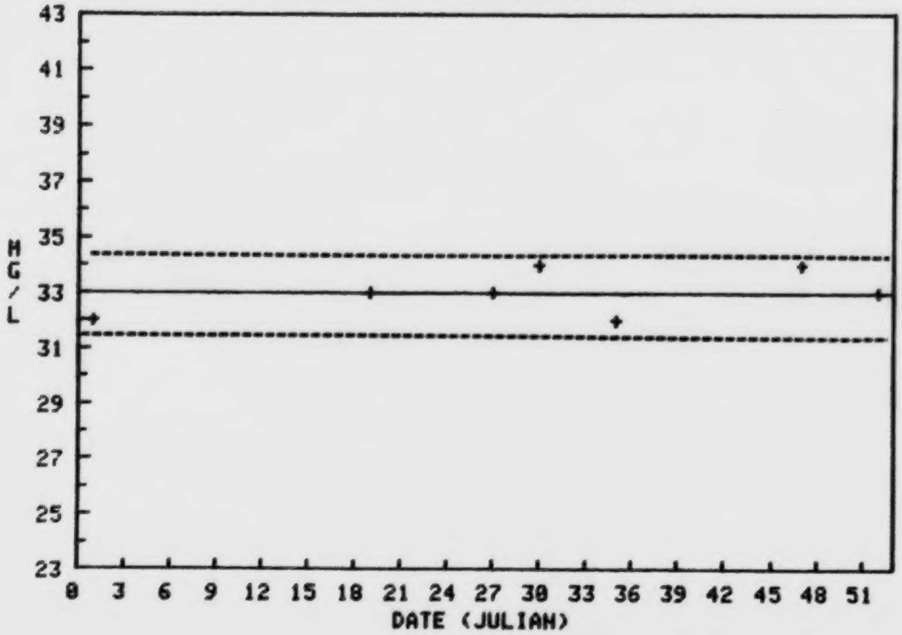
48
51
DATE (JULIAN)



MAGNESIUM: LOW CONCENTRATION



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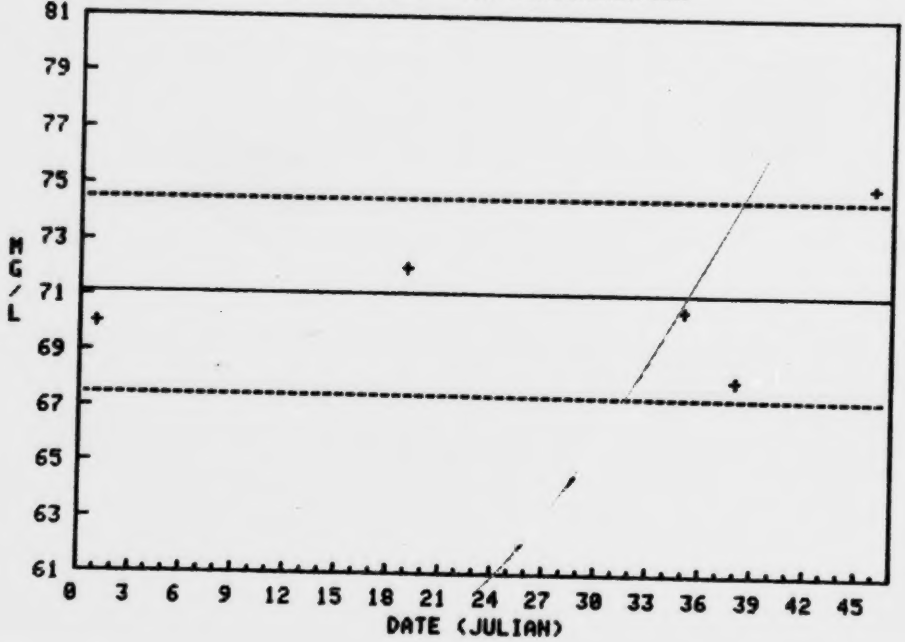
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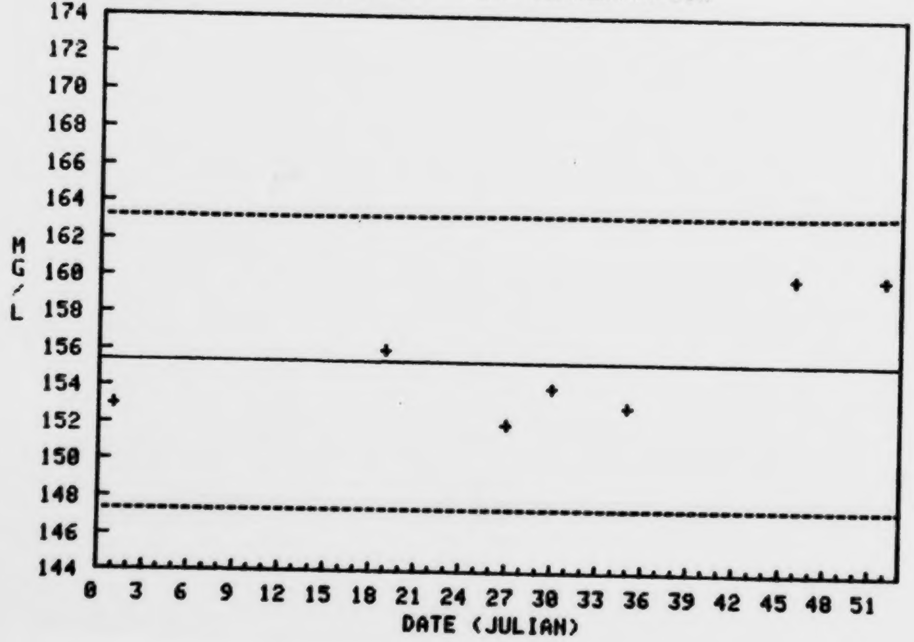
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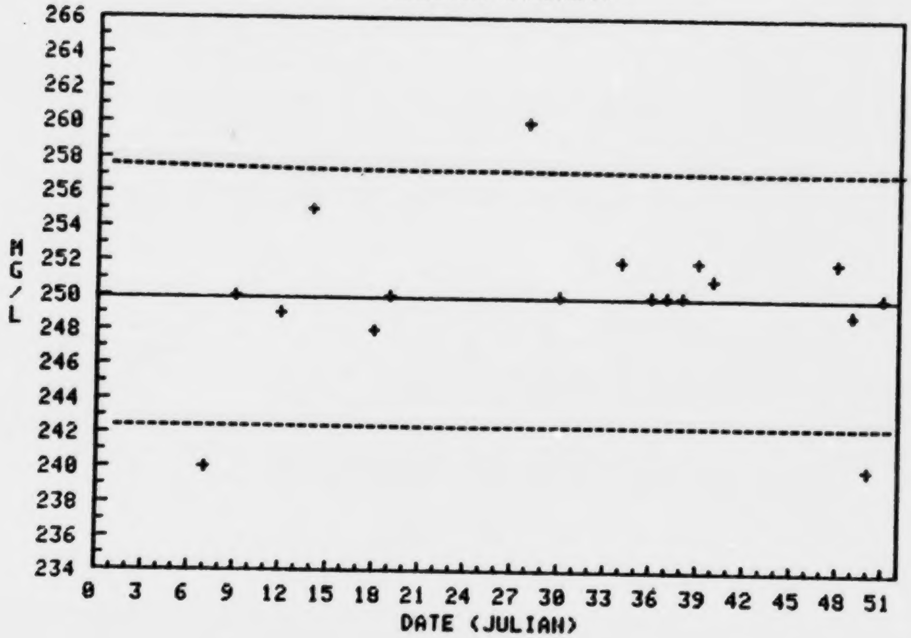
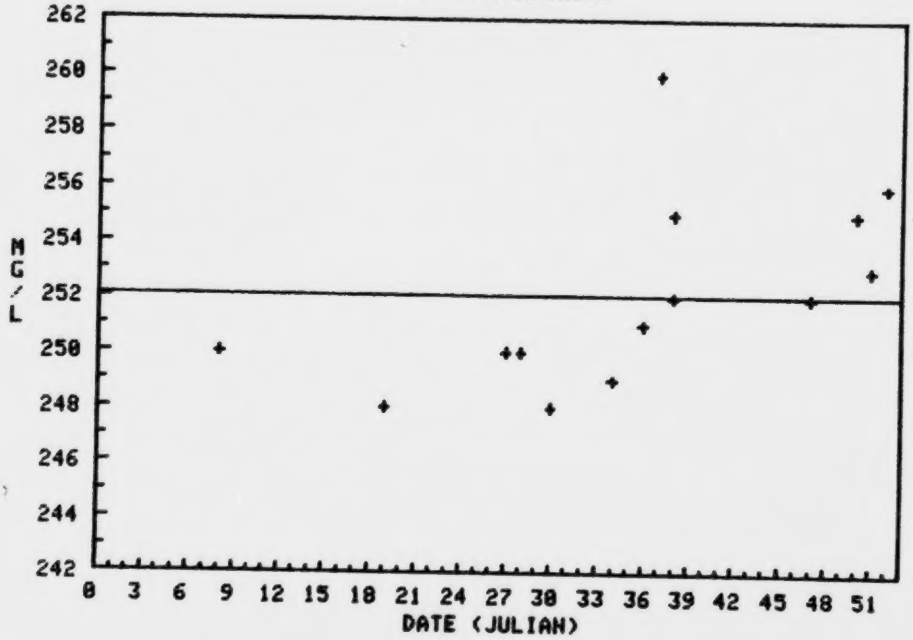


CALCIUM HARDNESS



TOTAL ALKALINITY

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DATE 113084
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APPENDIX D

ASH SLUICE MODEL FORTRAN CODE

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FURPUR 28R3A S74T11 11/30/84 14:29:49
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```
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      BLOCK DATA
      COMMON /ECONTS/A(100)         ,B(100)       ,C(100)       ,D(100)
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     2 ,SB(30)       ,SC(30)        ,SD(30)       ,K25L(100)    ,K25S(30)
     3 ,K25P(10)
C
      REAL          K25L            ,K25S         ,K25P
C
      REAL          NHY
C
      COMMON /EQVAL /TH1            ,TH2          ,BETA         ,ETA(100,30)
     1 ,TH(30)
C
      COMMON /GAMMCF/AD(100)        ,BD(100)      ,UD(100)      ,AI(30)
     1 ,BI(30)
C
      COMMON /COUNTS/NAVCAT         ,NAVAN        ,NAVSOL       ,NCAT
     1 ,NAN          ,NAVSPE
C
      COMMON /GAMD  /DGLN(30)       ,DGLND(100)   ,IZI(30)      ,IZD(100)
C
      COMMON /SOLIDS/LOCSDS         ,CKS(30)      ,NHY(30)      ,ESK(30,30)
     1 ,ISK(30)      ,APS(30)
      COMMON/LCMN/XMW(100),DHF(100),ENTO(100),ACP(100),BCP(100),CCP(100)
     *             ,DCP(100),TMIN(100),TMAX(100),ZE(100),ALIT(100),
     *             BLIT(100),UCAP(100),SPGR(25)
      COMMON/STRMS/ISTM1(15,10),ISTMX(15,10),IORDR1(8,33),IORDR2(8,33),
     *             NSV(25)
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     *             2*7,12,14,15,10*0,11,8,38*0/
      DATA ISTMX/4*5,19,18,19,7*1,2,18,19,18,19,3*0,7*2,16,7*0,3,4,3,5,
     *             3,4,3,10*0,4,0,2*5,4,14*0,5,0,14*6,17,14*7,0,2*11,
     *             2*20,11,2*20,7*8,9*0,2*9,2*0,2*9,16*0/
      DATA IORDR1/16,20,24,18,28,22,26,30,8*1,8*1H,,8*2,8*1H,,7,3,4,
     *              7,2*3,4,3,1H(,2*1H,,1H(,4*1H,,8,2*7,8,4,2*7,4,
     *              1H,,2*1H(,2*1H,,2*1H(,1H,,12,2*8,12,7,2*8,7,4*1H,,
     *              1H(,2*1H,,1H(,13,12,9,13,8,12,9,8,8*1H,,6,13,10,14,
     *              9,13,10,9,8*1H,,7,6,11,6,10,14,11,10,1H),7*1H,,1H ,
     *              15,12,7,11,6,12,11,1H ,2*1H,,1H),4*1H,,1H ,7,13,1H ,
     *              12,15,13,12,1H ,1H),1H,,1H ,4*1H,,2*1H ,6,1H ,13,7,
     *          14,13,2*1H ,1H,,1H ,1H,,1H),2*1H,,2*1H ,7,1H ,6,1H ,
     *          6,14,2*1H ,1H),1H ,1H,,1H ,2*1H,,4*1H ,15,1H ,7,6,
     *          4*1H ,1H,,1H ,1H),1H,,4*1H ,7,2*1H ,15,4*1H ,1H),
     *          2*1H ,1H,,7*1H ,7,7*1H ,1H),16*1H /
      DATA IORDR2/18,22,26,20,30,24,28,32,8*1,8*1H,,8*2,8*1H,,5,3,4,
     *          5,2*3,4,3,8*1H,,7,2*5,7,4,2*5,4,1H(,2*1H,,1H(,4*1H,,
     *          8,2*7,8,5,2*7,5,1H,,2*1H(,2*1H,,2*1H(,1H,,12,2*8,
     *          12,7,2*8,7,4*1H,,1H(,2*1H,,1H(,13,12,9,13,8,12,9,8,
     *          8*1H,,6,13,10,14,9,13,10,9,8*1H,,7,6,11,6,10,14,11,
     *          10,1H),7*1H,,1H ,15,12,7,11,6,12,11,1H ,2*1H,,1H),
     *          4*1H,,1H ,7,13,1H ,12,15,13,12,1H ,1H),1H,,1H ,4*1H,,
     *          2*1H ,6,1H ,13,7,14,13,2*1H ,1H,,1H ,1H,,1H),2*1H,,
     *          2*1H ,7,1H ,6,1H ,6,14,2*1H ,1H),1H ,1H,,1H ,2*1H,,
     *          4*1H ,15,1H ,7,6,4*1H ,1H,,1H ,1H),1H,,4*1H ,7,2*1H ,
     *          15,4*1H ,1H),2*1H ,1H,,7*1H ,7,7*1H ,1H)/
      DATA TMIN/100*298./,TMAX/100*333./
      DATA  XMW(4)/   44.011/, DHF(4)/  -94010./,ENTO(4)/  51.030/,
     6      XMW( 1)/   28.016/, DHF( 1)/        0./,ENTO( 1)/  45.770/,
     4      XMW(2)/   32.000/, DHF(2)/        0./,ENTO(2)/  48.970/,
     8      XMW( 3)/   18.016/, DHF( 3)/  -57770./,ENTO( 3)/  45.070/
     0DATA  XMW(26)/   74.096/, DHF(26)/ -235600./,ENTO(26)/  19.920/,
     1      XMW(27)/  100.091/, DHF(27)/ -288110./,ENTO(27)/  22.190/,
     3     XMW(28)/310.18/,DHF(28)/-9.882E5/,ENTO(28)/56.4/,
     4      XMW(29)/  136.146/, DHF(29)/ -340190./,ENTO(29)/  25.490/,
     5      XMW(30)/  172.178/, DHF(30)/ -482400./,ENTO(30)/  46.3  /,
     7      XMW(31)/   58.336/, DHF(31)/ -221000./,ENTO(31)/  15.10 /,
     *      XMW(32)/  174.411/, DHF(32)/-6.02E5  /,ENTO(32)/  50.0  /,
     1     XMW(33)/287.00/,DHF(33)/-1.340E6/,ENTO(33)/110./,
     2   XMW(34)/134.2/,DHF(34)/-377400./,ENTO(34)/20.9/,
     3     XMW(35)/60.080/,DHF(35)/-2.173E5/,ENTO(35)/10.6/,
     4     XMW(36)/172.09/,DHF(36)/-4.352E5/,ENTO(36)/21.0/,
     5     XMW(37)/105.99/,DHF(37)/-2.703E5/,ENTO(37)/32.5/,
     6      XMW(38)/   75.800/, DHF(38)/ -242547./,ENTO(38)/  11.240/,
     *      TMIN( 4)/    298./,TMAX( 4)/    1973./,ACP( 4)/    6.580/,
     4      TMIN( 2)/    298./,TMAX( 2)/    2973./,ACP( 2)/    6.530/,
     6      TMIN( 1)/    298./,TMAX( 1)/    2000./,ACP( 1)/    6.300/,
     8      TMIN( 3)/    298./,TMAX( 3)/    2973./,ACP( 3)/    6.780/
     0DATA  TMIN(26)/    298./,TMAX(26)/     973./,ACP(26)/   25.130/,
     1      TMIN(27)/    298./,TMAX(27)/     973./,ACP(27)/   24.970/,
     *     TMIN(28)/298./,TMAX(28)/333./,ACP(28)/70./,
     4      TMIN(29)/    298./,TMAX(29)/     973./,ACP(29)/   17.220/,
     5      TMIN(30)/    298./,TMAX(30)/     373./,ACP(30)/   44.5  /,
     7      TMIN(31)/    298./,TMAX(31)/    1000./,ACP(31)/   17.526/,
     *     TMIN(32)/298.    /,TMAX(32)/ 373.   /,ACP(32)/   40.0  /,
     1    TMIN(33)/298./,TMAX(33)/333./,ACP(33)/90./,
     2    TMIN(34)/298./,TMAX(34)/333./,ACP(34)/80./,
     3    TMIN(35)/298./,TMAX(35)/973./,ACP(35)/10.87/,
     4    TMIN(36)/298./,TMAX(36)/333./,ACP(36)/39.00/,
     5    TMIN(37)/298./,TMAX(37)/973./,ACP(37)/28.90/,
     6     TMIN(38)/    298./,TMAX(38)/    800./,ACP(38)/   14.920/
     0DATA  BCP( 4)/ 9.130E-3/,CCP( 4)/ -2.650E-6/,DCP( 4)/    0.0  /,
     6     BCP( 1)/ 1.830E-3/,CCP( 1)/ -3.300E-7/,DCP( 1)/    0.0  /,
     4     BCP( 2)/ 2.060E-3/,CCP( 2)/ -3.600E-7/,DCP( 2)/    0.0  /,
     8     BCP( 3)/ 3.570E-3/,CCP( 3)/ -4.600E-7/,DCP( 3)/    0.0  /,
     *     BCP(26)/ 2.880E-3/,CCP(26)/         0./,DCP(26)/  4.51E+5/,
     1     BCP(27)/ 5.240E-3/,CCP(27)/         0./,DCP(27)/  6.20E+5/,
     *    BCP(28)/.000/,CCP(28)/.000/,DCP(28)/.00/,
     4     BCP(29)/23.370E-3/,CCP(29)/         0./,DCP(29)/  0.33E+5/,
     5     BCP(30)/        0./,CCP(30)/         0./,DCP(30)/   0.0  /,
     7     BCP(31)/14.522E-3/,CCP(31)/         0./,DCP(31)/ 3.076E+5/,
     *     BCP(32)/        0./,CCP(32)/         0./,DCP(32)/    0.0  /,
     1    BCP(33)/.000/,CCP(33)/.000/,DCP(33)/.00/,
     2    BCP(34)/.000/,CCP(34)/.000/,DCP(34)/.00/,
     3    BCP(35)/.008/,CCP(35)/.000/,DCP(35)/-2.41E5/,
     4    BCP(36)/.000/,CCP(36)/.000/,DCP(36)/.00/,
     5    BCP(37)/.002/,CCP(37)/.000/,DCP(37)/.01/,
     6     BCP(38)/ 7.900E-3/,CCP(38)/         0./,DCP(38)/  3.61E+5/
     0DATA ALIT(46)/0.0        /,BLIT(46)/0.0        /,ZE(46)/ 0.     /,
     1    ALIT(47)/6.0        /,BLIT(47)/0.4        /,ZE(47)/+1.     /,
     2    ALIT(48)/3.0        /,BLIT(48)/0.3        /,ZE(48)/-1.     /,
     4    ALIT(49)/0.0        /,BLIT(49)/0.0        /,ZE(49)/ 0.     /,
     6    ALIT(50)/4.5        /,BLIT(50)/0.0        /,ZE(50)/-1.     /,
     7    ALIT(51)/0.0/,BLIT(51)/0.0/,ZE(51)/0.0/,UCAP(51)/.076/,
     1    ALIT(52)/3.0/,BLIT(52)/0.3/,ZE(52)/-2./,UCAP(52)/.000/,
     9    ALIT(53)/3.0        /,BLIT(53)/0.3        /,ZE(53)/-1.     /,
     2    ALIT(54)/3.0/,BLIT(54)/0.3/,ZE(54)/-1./,UCAP(54)/.000/,
     3    ALIT(55)/3.0        /,BLIT(55)/0.3        /,ZE(55)/+1.     /,
     4    ALIT(56)/3.0        /,BLIT(56)/0.3        /,ZE(56)/+1.     /,
     5    ALIT(57)/0.0        /,BLIT(57)/0.0        /,ZE(57)/ 0.     /,
     2    ALIT(58)/3.0        /,BLIT(58)/0.3        /,ZE(58)/+1.     /,
     1    ALIT(59)/0.0        /,BLIT(59)/0.0        /,ZE(59)/ 0.     /,
     4    ALIT(60)/3.0        /,BLIT(60)/0.3        /,ZE(60)/+1.     /,
     6    ALIT(61)/3.0        /,BLIT(61)/0.3        /,ZE(61)/+1.     /,
     8    ALIT(62)/0.0        /,BLIT(62)/0.0        /,ZE(62)/ 0.     /,
     7    ALIT(63)/0.0        /,BLIT(63)/0.0        /,ZE(63)/.0      /
     0DATA ALIT(64)/0.0        /,BLIT(64)/0.0        /,ZE(64)/ 0.     /,
     2      ALIT(65)/0.0       /,BLIT(65)/0.0       /,ZE(65)/ 0.      /,
     1      ALIT(66)/3.0       /,BLIT(66)/0.3       /,ZE(66)/-1.      /,
     4      ALIT(67)/0.0       /,BLIT(67)/0.0       /,ZE(67)/ 0.      /,
     3      ALIT(68)/3.0       /,BLIT(68)/0.3       /,ZE(68)/-1.      /,
     3      ALIT(69)/3.0/,BLIT(69)/0.3/,ZE(69)/.00/,UCAP(69)/.076/,
     4      ALIT(70)/3.0/,BLIT(70)/0.3/,ZE(70)/-1./,UCAP(70)/.000/,
     5      ALIT(71)/3.0/,BLIT(71)/0.3/,ZE(71)/.00/,UCAP(71)/.076/,
     6      ALIT(72)/3.0/,BLIT(72)/0.3/,ZE(72)/-1./,UCAP(72)/.000/,
     7      ALIT(73)/3.0/,BLIT(73)/0.3/,ZE(73)/.00/,UCAP(73)/.076/,
     8      ALIT(74)/3.0/,BLIT(74)/0.3/,ZE(74)/.00/,UCAP(74)/.076/,
     9      ALIT(75)/3.0/,BLIT(75)/0.3/,ZE(75)/-1./,UCAP(75)/.000/
      DATA ALIT(76)/3.0/,BLIT(76)/0.3/,ZE(76)/-2./,UCAP(76)/.000/,
     1      ALIT(77)/3.0/,BLIT(77)/0.3/,ZE(77)/1.0/,UCAP(77)/.000/,
     2      ALIT(78)/3.0/,BLIT(78)/0.3/,ZE(78)/.00/,UCAP(78)/.076/,
     3      ALIT(79)/3.0/,BLIT(79)/0.3/,ZE(79)/-1./,UCAP(79)/.000/,
     4      ALIT(80)/3.0/,BLIT(80)/0.3/,ZE(80)/.00/,UCAP(80)/.076/,
     5      ALIT(81)/3.0/,BLIT(81)/0.3/,ZE(81)/-1./,UCAP(81)/.000/,
     6      ALIT(82)/3.0/,BLIT(82)/0.3/,ZE(82)/-1./,UCAP(82)/.000/,
     2      ALIT(83)/4.5       /,BLIT(83)/0.1       /,ZE(83)/+2.      /,
     3      ALIT(84)/3.0       /,BLIT(84)/0.3       /,ZE(84)/+2.      /,
     9      ALIT(85)/5.0       /,BLIT(85)/0.1       /,ZE(85)/+1.      /,
     7      ALIT(86)/2.5/,BLIT(86)/.10/,ZE(86)/1.0/,UCAP(86)/.000/,
     8      ALIT(87)/5.0/,BLIT(87)/.10/,ZE(87)/1.0/,UCAP(87)/.000/,
     * ALIT(88)/4.0/, BLIT(88)/.00/, ZE(88)/-1.0/,
     7      ALIT(89)/4.5       /,BLIT(89)/0.0       /,ZE(89)/-2.      /,
     8      ALIT(90)/2.0       /,BLIT(90)/-.2       /,ZE(90)/-1.      /,
     5      ALIT(91)/3.0       /,BLIT(91)/0.0       /,ZE(91)/-2.      /,
     9      ALIT(92)/.00/,BLIT(92)/.00/,ZE(92)/.00/,UCAP(92)/.000/,
     A      ALIT(93)/3.0/,BLIT(93)/.00/,ZE(93)/-3./,UCAP(93)/.000/
     0DATA UCAP(46)/0.0       /,DHF(46)/-68317.   /,XMW(46)/ 18.016 /,
     1      UCAP(47)/0.0       /,DHF(47)/   0.0   /,XMW(47)/  1.008  /,
     2      UCAP(48)/0.0       /,DHF(48)/-54799.   /,XMW(48)/ 17.008  /,
     4      UCAP(49)/0.076     /,DHF(49)/-166971.  /,XMW(49)/ 62.027 /,
     6      UCAP(50)/0.0       /,DHF(50)/-164729.  /,XMW(50)/ 61.019 /,
     9      UCAP(53)/0.0       /,DHF(53)/-211660.  /,XMW(53)/ 97.074 /,
     3      UCAP(55)/0.0       /,DHF(55)/-183320.  /,XMW(55)/ 57.088 /,
     6      UCAP(56)/0.0       /,DHF(56)/-293118.  /,XMW(56)/101.099 /,
     5      UCAP(57)/0.076     /,DHF(57)/-289720.  /,XMW(57)/100.091 /,
     8      UCAP(58)/0.0       /,DHF(58)/-173445.  /,XMW(58)/102.088 /,
     7      UCAP(59)/0.076     /,DHF(59)/-344033.  /,XMW(59)/136.146 /,
     9      UCAP(60)/0.0       /,DHF(60)/-162839.  /,XMW(60)/ 41.328 /,
     2      UCAP(61)/0.0       /,DHF(61)/-274063.  /,XMW(61)/ 85.339 /,
     4      UCAP(62)/0.076     /,DHF(62)/-270226.  /,XMW(62)/ 84.331 /,
     3      UCAP(63)/0.076      /,DHF(63)/-322469.  /,XMW(63)/120.386 /,
     6      UCAP(64)/0.076      /,DHF(64)/-112078.  /,XMW(64)/ 39.999 /,
     8      UCAP(65)/0.076      /,DHF(65)/-222008.  /,XMW(65)/ 84.01  /,
     7      UCAP(66)/0.0        /,DHF(66)/-218017.  /,XMW(66)/ 83.002 /
     0DATA  UCAP(67)/0.076      /,DHF(67)/-106651.  /,XMW(67)/ 84.999 /,
     9      UCAP(68)/0.0        /,DHF(68)/-273076.  /,XMW(68)/119.057 /,
     2      UCAP(83)/0.0        /,DHF(83)/-129770.  /,XMW(83)/ 40.08  /,
     9      UCAP(84)/0.0        /,DHF(84)/-110410.  /,XMW(84)/ 24.32  /,
     5      UCAP(85)/0.0        /,DHF(85)/- 57279.  /,XMW(85)/ 22.991 /,
     1      UCAP(88)/0.0        /,DHF(88)/- 40023.  /,XMW(88)/ 35.457 /,
     7      UCAP(89)/0.0        /,DHF(89)/-162126.  /,XMW(89)/ 60.011 /,
     8      UCAP(90)/0.0        /,DHF(90)/- 49372.  /,XMW(90)/ 62.008 /,
     5      UCAP(91)/0.0        /,DHF(91)/-216900.  /,XMW(91)/ 96.066 /
     0DATA  TMIN(46)/       273./,TMAX(46)/     373./,ACP(46)/      18.04/,
     1      TMIN(47)/       298./,TMAX(47)/     333./,ACP(47)/      23.00/,
     2      TMIN(48)/       298./,TMAX(48)/     333./,ACP(48)/    - 47.00/,
     3      TMIN(49)/       298./,TMAX(49)/     333./,ACP(49)/      91.00/,
     6      TMIN(50)/       298./,TMAX(50)/    333./,ACP(50)/    - 27.00/,
     9      TMIN(53)/       298./,TMAX(53)/     333./,ACP(53)/   - 13.00/ ,
     3      TMIN(55)/       298./,TMAX(55)/     333./,ACP(55)/   -  2.00/,
     6      TMIN(56)/       298./,TMAX(56)/     333./,ACP(56)/     18.00/,
     5      TMIN(57)/       298./,TMAX(57)/     333./,ACP(57)/   - 87.00/,
     8      TMIN(58)/       298./,TMAX(58)/     333./,ACP(58)/   -  4.00/,
     7      TMIN(59)/       298./,TMAX(59)/     333./,ACP(59)/   -  8.00/
     0DATA  TMIN(60)/       298./,TMAX(60)/     333./,ACP(60)/      4.00/,
     2      TMIN(61)/       298./,TMAX(61)/     333./,ACP(61)/     24.00/,
     4      TMIN(62)/       298./,TMAX(62)/     333./,ACP(62)/   - 81.00/,
     3      TMIN(63)/       298./,TMAX(63)/     333./,ACP(63)/   - 48.00/,
     6      TMIN(64)/       298./,TMAX(64)/     333./,ACP(64)/   - 12.00/,
     8      TMIN(65)/       298./,TMAX(65)/     333./,ACP(65)/      8.00/,
     7      TMIN(66)/       298./,TMAX(66)/     333./,ACP(66)/   - 97.00/,
     8      TMIN(67)/       298./,TMAX(67)/     333./,ACP(67)/   - 14.00/,
     9      TMIN(68)/       298./,TMAX(68)/     333./,ACP(68)/   - 64.00/ ,
     2      TMIN(83)/       298./,TMAX(83)/     333./,ACP(83)/     45.00/,
     9      TMIN(84)/       298./,TMAX(84)/     333./,ACP(84)/     51.00/,
     5      TMIN([illegible]/       298./,TMAX(85)/     333./,ACP(85)/     35.00/,
     1      TMIN(88)/       298./,TMAX(88)/     333./,ACP(88)/   - 51.00/ ,
     7      TMIN(89)/       298./,TMAX(89)/    333./,ACP(89)/    -132.00/,
     8      TMIN(90)/       298./,TMAX(90)/     333./,ACP(90)/   - 49.00/,
     5      TMIN(91)/       298./,TMAX(91)/     333./,ACP(91)/   - 99.00/
      DATA  XMW(51)/63.01/,DHF(51)/-4.96E4/,ACP(51)/10.00/,
     1      XMW(52)/94.10/,DHF(52)/-3.50E5/,ACP(52)/ .0  /,
     2      XMW(54)/95.11/,DHF(54)/-3.50E5/,ACP(54)/.0000/,
     3      XMW(69)/17.03/,DHF(69)/-1.92E4/,ACP(69)/.0000/,
     4      XMW(70)/114.1/,DHF(70)/-2.40E5/,ACP(70)/.0000/,
     5      XMW(71)/115.1/,DHF(71)/-2.44E5/,ACP(71)/-.900/,
     6      XMW(72)/78.05/,DHF(72)/-2.00E5/,ACP(72)/.0000/,
     7      XMW(73)/79.06/,DHF(73)/-1.97E5/,ACP(73)/.0000/,
     8      XMW(74)/98.00/,DHF(74)/-3.08E5/,ACP(74)/.0000/,
     9      XMW(75)/96.99/,DHF(75)/-3.10E5/,ACP(75)/.0000/
      DATA  XMW(76)/95.98/,DHF(76)/-3.09E5/,ACP(76)/.0000/,
     1      XMW(77)/94.97/,DHF(77)/-4.40E5/,ACP(77)/.0000/,
     2      XMW(78)/136.1/,DHF(78)/-4.39E5/,ACP(78)/.0000/,
     3      XMW(79)/135.1/,DHF(79)/-4.40E5/,ACP(79)/.0000/,
     4      XMW(80)/120.3/,DHF(80)/-4.20E5/,ACP(80)/.0000/,
     5      XMW(81)/60.02/,DHF(81)/-1.00E5/,ACP(81)/.0000/,
     6      XMW(82)/135.1/,DHF(82)/-2.00E5/,ACP(82)/.0000/,
     7      XMW(86)/18.04/,DHF(86)/-3.17E4/,ACP(86)/19.10/,
     8      XMW(87)/39.10/,DHF(87)/-6.00E4/,ACP(87)/2.300/,
     9      XMW(92)/96.12/,DHF(92)/-3.51E5/,ACP(92)/.0000/,
     A      XMW(93)/94.97/,DHF(93)/-3.05E5/,ACP(93)/.0000/
      DATA SPGR/2.24,2.71,3.14,2.61,2.32,2.36,1.73,3.00,2.50,2.20,2.31,
     * 2.53,3.28,12*.0/
C
C
C
C
      DATA NAVCAT/6/,NAVAN/6/,LOCSDS/13/,NAVSPE/35/,NAVSOL/11/
C
      DATA ETA/3000*.0/,ESK/900*.0/
      DATA ETA(1,1)/-1./
      DATA ETA(2,1)/2./,ETA(2,8)/1./
      DATA ETA(3,1)/1./,ETA(3,8)/1./
      DATA ETA(4,1)/1./,ETA(4,9)/1./
      DATA ETA(5,1)/-2./,ETA(5,11)/1./
      DATA ETA(6,1)/1./,ETA(6,10)/1./
      DATA ETA(7,1)/-1./,ETA(7,11)/1./
      DATA ETA(8,1)/-1./,ETA(8,2)/1./
      DATA ETA(9,1)/1./,ETA(9,2)/1./,ETA(9,8)/1./
      DATA ETA(10,2)/1./,ETA(10,8)/1./
      DATA ETA(11,2)/1./,ETA(11,9)/1./
      DATA ETA(12,2)/1./,ETA(12,10)/1./
      DATA ETA(13,1)/-1./,ETA(13,3)/1./
      DATA ETA(14,1)/1./,ETA(14,3)/1./,ETA(14,8)/1./
      DATA ETA(15,3)/1./,ETA(15,8)/1./
      DATA ETA(16,3)/1./,ETA(16,10)/1./
      DATA ETA(17,1)/-1./,ETA(17,4)/1./
      DATA ETA(18,1)/1./,ETA(18,4)/1./,ETA(18,8)/1./
      DATA ETA(19,4)/1./,ETA(19,8)/1./
      DATA ETA(20,4)/1./,ETA(20,9)/1./
      DATA ETA(21,4)/1./,ETA(21,10)/1./
      DATA ETA(22,1)/-1./,ETA(22,5)/1./
      DATA ETA(23,5)/1./,ETA(23,10)/1./
      DATA ETA(24,1)/1./,ETA(24,5)/1./,ETA(24,10)/1./
      DATA ETA(25,5)/1./,ETA(25,8)/1./
      DATA ETA(26,1)/1./,ETA(26,5)/1./,ETA(26,8)/1./
      DATA ETA(27,1)/3./,ETA(27,12)/1./
      DATA ETA(28,1)/2./,ETA(28,12)/1./
      DATA ETA(29,1)/1./,ETA(29,12)/1./
      DATA ETA(30,1)/2./,ETA(30,2)/1./,ETA(30,12)/1./
      DATA ETA(31,1)/1./,ETA(31,2)/1./,ETA(31,12)/1./
      DATA ETA(32,2)/1./,ETA(32,12)/1./
      DATA ETA(33,1)/1./,ETA(33,3)/1./,ETA(33,12)/1./
      DATA ETA(34,5)/1./,ETA(34,8)/1./
      DATA ETA(35,6)/1./,ETA(35,10)/1./
C
C
C
      DATA ESK(1,1)/-2./,ESK(1,2)/1./
      DATA ESK(2,2)/1./,ESK(2,8)/1./
      DATA ESK(3,2)/3./,ESK(3,12)/2./
      DATA ESK(4,2)/1./,ESK(4,10)/1./
      DATA ESK(5,2)/1./,ESK(5,10)/1./
      DATA ESK(6,1)/-2./,ESK(6,3)/1./
      DATA ESK(7,3)/1./,ESK(7,8)/1./
      DATA ESK(8,1)/-4./,ESK(8,3)/2./,ESK(8,11)/3./
      DATA ESK(9,1)/-2./,ESK(9,2)/1./,ESK(9,11)/1./
      DATA ESK(10,11)/1./
      DATA ESK(11,2)/1./,ESK(11,1)/1./,ESK(11,12)/1./
C
C
C
      DATA IZI(1)/1/,AI(1)/.0875/,BI(1)/.103/,
     1 IZI(2)/2/,AI(2)/.0374/,BI(2)/.119/,
     2 IZI(3)/2/,AI(3)/.057/,BI(3)/.157/,
     3 IZI(4)/1/,AI(4)/.0/,BI(4)/.028/,
     4 IZI(5)/1/,AI(5)/-.0420/,BI(5)/-.020/,
     5 IZI(6)/1/,AI(6)/-.045/,BI(6)/-.079/,
     6 IZI(7)/-1/,AI(7)/.0643/,BI(7)/-.067/,
     7 IZI(8)/-2/,AI(8)/.028/,BI(8)/-.67/,
     8 IZI(9)/-1/,AI(9)/-.025/,BI(9)/.27/,
     9 IZI(10)/-2/,AI(10)/.0/,BI(10)/-.40/,
     A IZI(11)/0/,AI(11)/.0/,BI(11)/.0/,
     B IZI(12)/-3/,AI(12)/.024/,BI(12)/-.70/,
     C AD(1)/.076/,BD(1)/-1./,
     D UD(2)/.168/,
     E AD(3)/.100/,BD(3)/.08/,
     F UD(4)/.0/,
     G AD(5)/.01/,BD(5)/-.7/,
     H AD(6)/-.05/,BD(6)/.35/,
     I AD(7)/-.04/,BD(7)/.05/,
     J AD(8)/-.05/,BD(8)/-.1/
      DATA  AD(9)/-.1/,BD(9)/-.1/,
     1 UD(10)/-.1/,
     2 AD(11)/-.1/,BD(11)/-.1/,
     $ UD(12)/.2/,
     4 AD(13)/-.07/,BD(13)/-.14/,
     5 AD(14)/-.1/,BD(14)/-.1/,
     6 UD(15)/-.1/,
     7 UD(16)/.2/,
     8 UD(17)/-.05/,
     $ UD(18)/.2/,
     A AD(19)/+.10/,BD(19)/.03/,
     B UD(20)/-.1/,
     C AD(21)/.10/,BD(21)/.25/,
     D UD(22)/.13/,
     E AD(23)/-.1/,BD(23)/.25/,
     F UD(24)/-.15/,
     G AD(25)/.10/,BD(25)/.03/,
     $ UD(26)/.2/,
     I UD(27)/-.15/,
     J AD(28)/-.052/,BD(28)/.20/
      DATA  AD(29)/-.01/,BD(29)/-.57/,
     1 AD(30)/-.15/,BD(30)/.0/,
     2 UD(31)/-.15/,
     6 AD(32)/-.03/,BD(32)/-.6/,
     3 UD(33)/-.15/,
     4 AD(34)/.1/,BD(34)/-.73/,
     5 AD(35)/-.1/,BD(35)/.25/
      DATA NHY/-2.,3*0.,2*2.,5.,-1.,0.,-2.,20*0./
C
C
```

```
C
      DATA A(1)/4471.0/,B(1)/.0000/,C(1)/.01706/
      DATA A(2)/6307.1/,B(2)/.0000/,C(2)/.05658/
      DATA A(3)/2902.4/,B(3)/.0000/,C(3)/.02379/
      DATA A(4)/320.88/,B(4)/.0000/,C(4)/.01359/
      DATA A(5)/-12355./,B(5)/.0/,C(5)/-.06593/
      DATA A(6)/475.14/,B(6)/.0/,C(6)/.01822/
      DATA A(7)/-3406./,B(7)/.0000/,C(7)/-.0163/
      DATA A(8)/-4744./,B(8)/.0000/,C(8)/-.0171/
      DATA A(9)/2600.6/,B(9)/.0000/,C(9)/.02379/
      DATA A(10)/-475.5/,B(10)/.0000/,C(10)/.00000/
      DATA A(11)/-1245./,B(11)/.0000/,C(11)/.00000/
      DATA A(12)/2572./,B(12)/23.15/,C(12)/.0/
      DATA A(13)/-4989./,B(13)/.0000/,C(13)/-.0171/
      DATA A(14)/2667.3/,B(14)/.0000/,C(14)/.02379/
      DATA A(15)/-504.8/,B(15)/.0000/,C(15)/.00000/
      DATA A(16)/173.740/,B(16)/9.5609/,C(16)/.0/
      DATA A(17)/-4471./,B(17)/.0000/,C(17)/-.0171/
      DATA A(18)/2902.4/,B(18)/.0000/,C(18)/.02379/
      DATA A(19)/-303.4/,B(19)/.0000/,C(19)/.00000/
      DATA A(20)/.00000/,B(20)/.0000/,C(20)/.00000/
      DATA A(21)/-241.0/,B(21)/.0000/,C(21)/.00000/
      DATA A(22)/-2727./,B(22)/.0/,C(22)/.00000/
      DATA A(23)/.00000/,B(23)/.0/,C(23)/.00000/
      DATA A(24)/.00000/,B(24)/.0/,C(24)/.00000/
      DATA A(25)/-585.2/,B(25)/.0/,C(25)/.00000/
      DATA A(26)/-1195./,B(26)/.0/,C(26)/.00000/
      DATA A(27)/2042.8/,B(27)/.0/,C(27)/.01751/
      DATA A(28)/2442.4/,B(28)/.0/,C(28)/.01751/
      DATA A(29)/666.63/,B(29)/.0/,C(29)/.00000/
      DATA A(30)/1699.3/,B(30)/.0/,C(30)/.01751/
      DATA A(31)/-54.67/,B(31)/.0/,C(31)/.00000/
      DATA A(32)/-677.6/,B(32)/.0/,C(32)/.00000/
      DATA A(33)/-54.67/,B(33)/.0/,C(33)/.00000/
      DATA A(34)/692.3/,B(34)/.0/,C(34)/-.024/
      DATA A(35)/.0/,B(35)/.0/,C(35)/-.005333/
      DATA D(1)/6.0875/,K25L(1)/1.0129E-14/
      DATA D(2)/21.341/,K25L(2)/1.2842E-21/
      DATA D(3)/6.4980/,K25L(3)/4.6817E-11/
      DATA D(4)/6.5370/,K25L(4)/2.5633E+01/
      DATA D(5)/-39.49/,K25L(5)/4.1300E+21/
      DATA D(6)/5.0435/,K25L(6)/1.0396E-02/
      DATA D(7)/-6.368/,K25L(7)/8.5660E+09/
      DATA D(8)/-8.378/,K25L(8)/4.1690E+12/
      DATA D(9)/4.2260/,K25L(9)/2.5750E-12/
      DATA D(10)/-4.795/,K25L(10)/6.2996E-04/
      DATA D(11)/-4.490/,K25L(11)/4.8485E-01/
      DATA D(12)/63.600/,K25L(12)/4.8969E-03/
      DATA D(13)/-10.41/,K25L(13)/2.5669E+11/
      DATA D(14)/4.7510/,K25L(14)/5.1504E-12/
      DATA D(15)/-5.091/,K25L(15)/3.9999E-04/
      DATA D(16)/22.134/,K25L(16)/.00781/
      DATA D(17)/-5.518/,K25L(17)/3.6679E+14/
      DATA D(18)/6.5045/,K25L(18)/4.7520E-11/
      DATA D(19)/-2.921/,K25L(19)/1.2500E-02/
      DATA D(20)/.40000/,K25L(20)/2.5119E+00/
      DATA D(21)/-1.529/,K25L(21)/1.9024E-01/
      DATA D(22)/.09730/,K25L(22)/1.7573E+09/
      DATA D(23)/-1.110/,K25L(23)/7.7600E-02/
      DATA D(24)/-2.983/,K25L(24)/1.0400E-03/
      DATA D(25)/-3.394/,K25L(25)/3.7057E-02/
      DATA D(26)/-14.22/,K25L(26)/6.0943E-11/
      DATA D(27)/-9.457/,K25L(27)/2.9611E-22/
      DATA D(28)/-5.969/,K25L(28)/4.1613E-20/
      DATA D(29)/-9.945/,K25L(29)/6.5976E-13/
      DATA D(30)/-9.871/,K25L(30)/1.6200E-21/
      DATA D(31)/-15.10/,K25L(31)/1.2010E-15/
      DATA D(32)/-8.733/,K25L(32)/3.4642E-07/
      DATA D(33)/-15.27/,K25L(33)/8.1200E-16/
      DATA D(34)/-4.17/,K25L(34)/4.00/
      DATA D(35)/-.789/,K25L(35)/6.31/
      DATA PA(1)/-1015./,PB(1)/.0/,PC(1)/.0/,PPD(1)/-4.87/,K25P(1)/.034/
      DATA PA(2)/.0000/,PB(2)/.0/,PC(2)/.0/,PPD(2)/4.763/,K25P(2)/6.E4/
      DATA PA(3)/-68.424/,PB(3)/28.1001/,PC(3)/-.021379/,
     $ PPD(3)/64.7125/,K25P(3)/60.86/
      DATA SA(1)/-8176.4/,SB(1)/4.470E-7/,SC(1)/-.016996/
      DATA SA(2)/-1660.0/,SB(2)/.0000000/,SC(2)/.0000000/
      DATA SA(3)/.000000/,SB(3)/.0000000/,SC(3)/.0000000/
      DATA SA(4)/701.810/,SB(4)/1.729E-6/,SC(4)/.0195566/
      DATA SA(5)/4944.0/,SB(5)/37.74500/,SC(5)/.0000000/
      DATA SA(6)/-9422.8/,SB(6)/.0000000/,SC(6)/-.03412/
      DATA SA(7)/-955.14/,SB(7)/.0000000/,SC(7)/.0000000/
      DATA SA(8)/.0/,SB(8)/.0/,SC(8)/.0/
      DATA SA(9)/.0/,SB(9)/.0/,SC(9)/.033/
      DATA SA(10)/.000000/,SB(10)/.0000000/,SC(10)/-.003007/
      DATA SA(11)/.000000/,SB(11)/.0000000/,SC(11)/.0000000/
```

```
              DATA SD(1)/-9.7510/,K25S(1)/5.6287E-06/
              DATA SD(2)/-13.880/,K25S(2)/4.8695E-09/
              DATA SD(3)/-26.000/,K25S(3)/1.0000E-26/
              DATA SD(4)/3.71500/,K25S(4)/2.4000E-05/
              DATA SD(5)/105.360/,K25S(5)/2.4000E-05/
              DATA SD(6)/-24.689/,K25S(6)/1.2550E-11/
              DATA SD(7)/-7.8710/,K25S(7)/2.1500E-05/
              DATA SD(8)/18.78/,K25S(8)/6.02E18/
              DATA SD(9)/3.274/,K25S(9)/2.72E-07/
              DATA SD(10)/-2.0686/,K25S(10)/.036300000/
              DATA SD(11)/-19.174/,K25S(11)/6.6000E-20/
              END

@PRT,S     X.XC0001/
```

```
390-1514*ASH(1).XC0001(11)
      COMPILER (STD=66)
      SUBROUTINE XC0001(LSV,DEL,LFLAG)
C
C
C
C
C
C
C
C
      DOUBLE PRECISION LABEL,IDEGP
      COMMON/CMMN/SV(25,130),IDEQP(20),ISTM(25,10),ISEQ(25),PA(20,24),
     *          L(2),NL,LSRL(2),LERL(2),WV,DNAT(4),XA(4),LABEL(13),
     *          AH2O
      COMMON/DEBUG/IPT
      COMMON/CIRC/ALKDES,DESVAL,QBD,KFLAG
      COMMON/FLAG/IFLAG
      COMMON/AACID/ACDTYP,NUMAC
      COMMON/RESEN/REN
      COMMON/SOLIDS/LOCSDS,CKS(30),NHY(30),ESK(30,30),ISK(30),APS(30)
      DIMENSION IOPT(34),PP(4),DEL(2)
      IF(IPT.EQ.5) CALL XSE006(LSV)
      ITRCNT=0
      IADD=0
      PRINT 2000,SV(LSV,40)
 2000 FORMAT(10X,'IN XC003  PH=',E10.3)
      DO 1 I=1,34
    1 IOPT(I)=0
      ICOUNT=0
      IOPT(1)=1
      IOPT(19)=1
      NS=1
      IFLAG=1
C
C
C
      IF(IPHG.NE.1) GO TO 3
      SV(LSV,40)=PHGUES
      PHLOW=PHGUES-1.0
      PHHIGH=PHGUES+1.0
      IBFLG=1
      GO TO 10
    3 CONTINUE
      CALL YEQ001(LSV,IOPT,SV(LSV,5),PP,WNES,NS)
      TOTALK=(2.0*(SV(LSV,52)+SV(LSV,57)+SV(LSV,61)+SV(LSV,84))
     1  +SV(LSV,42)+SV(LSV,45)+SV(LSV,50)+SV(LSV,51)+SV(LSV,55)
     2  +SV(LSV,56)+SV(LSV,59)+SV(LSV,60)+SV(LSV,42))/2.0*100.08*1000.
      IF(ABS(TOTALK-DESVAL)/DESVAL.LE.0.05) GO TO 20
      PRINT 2001,SV(LSV,40),DESVAL,TOTALK
 2001 FORMAT(10X,'FIRST CALL TO YEQ001 PH DESVAL ALK',3E10.4)
      IF(TOTALK-DESVAL) 6,20,7
    6 CONTINUE
C
      NUMAC=22
      ACDTYP=3.0
   21 CONTINUE
      PHLOW=SV(LSV,40)
      SV(LSV,40)=PHLOW+2.0
      IACD=1
      GO TO 10
    7 CONTINUE
C
      IF(ACDTYP.EQ.0.0) NUMAC=28
      IF(ACDTYP.EQ.1.0) NUMAC=26
      IF(ACDTYP.EQ.2.0) NUMAC=25
   22 CONTINUE
      PHHIGH=SV(LSV,40)
      SV(LSV,40)=PHHIGH-3.0
      IACD=2
   10 CONTINUE
      IF(IADD.EQ.0) ACDINI=SV(LSV,NUMAC)
      IADD=1
      PRINT 2002,ITRCNT,PHLOW,PHHIGH,SV(LSV,40),IBFLG,TOTALK
 2002 FORMAT(10X,'ITER',I3,'PHLOW PHHIGH PH',3E10.3,'B',I3,'ALK',E10.3)
      XX2=SV(LSV,NUMAC)
      XX1=1.1*XX2
      ER=REN
      ITRCNT=ITRCNT+1
      IF(ITRCNT.GT.15) GO TO 1000
C
      DO 9 I=1,10
      IF(I.EQ.1) GO TO 8
      IF(ABS(REN).LT.1.E-6) GO TO 12
      DER=(REN-ER)/(XX1-XX2)
      XX2=XX1
      ER=REN
      XX1=XX1-ER/DER
    8 SV(LSV,NUMAC)=XX1
    9 CALL YEQU01(LSV,IOPT,SV(LSV,5),PP,WNES,NS)
      PRINT 1001,SV(LSV,40)
 1001 FORMAT(//,5X,15H*****ERROR*****,//,2X,
     * 51HXC003 COULD NOT FIND AN ADDITION RATE TO ACHIEVE A ,F4.2,
     * 20H PH IN 10 ITERATIONS)
       STOP
   12 CONTINUE
      TOTALK=(2.0*(SV(LSV,52)+SV(LSV,57)+SV(LSV,61)+SV(LSV,84))
     1  +SV(LSV,42)+SV(LSV,45)+SV(LSV,50)+SV(LSV,51)+SV(LSV,55)
     2  +SV(LSV,56)+SV(LSV,59)+SV(LSV,60)+SV(LSV,42))/2.0*100.08*1000.
      IF(ABS(TOTALK-DESVAL)/DESVAL.LE.0.05) GO TO 20
      IF(IBFLG.EQ.1) GO TO 24
      IF(IACD.EQ.1) GO TO 4
C
C
      IF(TOTALK.LT.DESVAL) GO TO 26
      GO TO 22
    4 CONTINUE
C
C
      IF(TOTALK.GT.DESVAL) GO TO 26
      GO TO 21
   26 CONTINUE
C
C
      IF(IACD.EQ.1) PHHIGH=SV(LSV,40)
      IF(IACD.EQ.2) PHLOW=SV(LSV,40)
      SV(LSV,40)=0.5*(PHHIGH+PHLOW)
      IBFLG=1
      GO TO 10
   24 CONTINUE
      ALKERR=TOTALK-DESVAL
      PHINT=SV(LSV,40)
      IF(ALKERR.GT.0.0) GO TO 25
      SV(LSV,40)=0.5*(PHHIGH+PHINT)
      PHLOW=PHINT
      GO TO 10
   25 CONTINUE
      SV(LSV,40)=0.5*(PHINT+PHLOW)
      PHHIGH=PHINT
      GO TO 10
 1000 PRINT 101
  101 FORMAT(10X,'COULD NOT CONVERGE ON ALKDES IN 15 ITERATIONS')
      STOP
C
C
C
   20 CONTINUE
      DEL(1)=SV(LSV,NUMAC)-ACDINI
      IF(ABS(DEL(1)).LE.1.E-6) DEL(1)=0.0
      LFLAG=1
      ICNT=ICNT+1
      KFLAG=0
      PHGUES=SV(LSV,40)
      IPHG=1
      RETURN
      END

@PRT,S    X.XC0002/
```

```
390-1514*ASH(1).XC0002(52)
            COMPILER (STD=66)
            SUBROUTINE XC0002(LSV,DEL,LFLAG)
C
C
C
C
C
            COMMON/CIRC/ALKDES,PHDES,QBD,KFLAG
C
C
C
            DOUBLE PRECISION LABEL,IDEQP
            COMMON/CMMN/SV(25,130),IDEQP(20),ISTM(25,10),ISEQ(25),PA(20,24),
           *           L(2),NL,LSRL(2),LERL(2),WV,DNAT(4),XA(4),LABEL(13),
           *           AH2O
            COMMON/FLAG/IFLAG
            COMMON/RESEN/REN
            COMMON/AACID/ACDTYP,NUMAC
            DIMENSION DEL(2),PP(4),IOPT(34)
            DO 1 I=1,34
      1     IOPT(I)=0
            DEL(1)=0.
            DEL(2)=0.
C
C
C
            IFLAG=1
            IOPT(19)=1
            NS=1
C
            IF(LFLAG.GT.0) ICNT=0
            IF(ICNT.GT.0) GO TO 2
C
            CALL YEQ001 (LSV,IOPT,SV(LSV,5),PP,WNES,NS)
C
            IF(SV(LSV,40)-PHDES) 3,13,5
          3 CONTINUE
C
            NUMAC=22
            GO TO 2
          5 CONTINUE
C
```

```
      IF(ACDTYP.EQ.0.0) NUMAC=28
      IF(ACDTYP.EQ.1.0) NUMAC=26
      IF(ACDTYP.EQ.2.0) NUMAC=25
    2 IOPT(1)=1
      SV(LSV,40)=PHDES
      ACI=SV(LSV,NUMAC)
C
C
      SV(LSV,40)=PHDES
      ACI=SV(LSV,NUMAC)
C
      CALL YEQUD1 (LSV,IOPT,SV(LSV,5),PP,WNES,NS)
C
      XX2=SV(LSV,NUMAC)
      XX1=1.1*XX2
      ER=REN
C
      DO 9 I=1,10
      IF(I.EQ.1) GO TO 8
      IF(ABS(REN).LT.1.E-6) GO TO 12
      DER=(REN-ER)/(XX1-XX2)
      XX2=XX1
      ER=REN
      XX1=XX1-ER/DER
C
C
    8 SV(LSV,NUMAC)=XX1
C
    9 CALL YEQUD1 (LSV,IOPT,SV(LSV,5),PP,WNES,NS)
C
      WRITE(6,10) PHDES
   10 FORMAT(//,5X,15H*****ERROR*****,//,2X,
     1 51HXCOD2 COULD NOT FIND AN ADDITION RATE TO ACHIEVE A ,F4.2,
     2 20H PH IN 10 ITERATIONS)
C
      STOP
C
C
   12 DEL(1)=SV(LSV,NUMAC)-ACI
      KFLAG=0
      ICNT=1
   13 RETURN
      END
```

DATE 113084

@PRT,S X.XC0003/

```
390-1514*ASH(1).XC0003(4)                                                    DATE 113084
      COMPILER (STD=66)
      SUBROUTINE XC0003(LSV,DEL,LFLAG)
C
C
C
C
C
C
C
C
      DOUBLE PRECISION LABEL,IDEQP
      COMMON/CMMN/SV(25,130),IDEQP(20),ISTM(25,10),ISEQ(25),PA(20,24),
     *             L(2),NL,LSRL(2),LERL(2),WV,DNAT(4),XA(4),LABEL(13),
     *             AH20
      COMMON/CIRC/ALKDES,DESVAL,QBD,KFLAG
      COMMON/FLAG/IFLAG
      COMMON/AACID/ACDTYP,NUMAC
      COMMON/RESEN/REN
      COMMON/SOLIDS/LOCSDS,CKS(30),NHY(30),ESK(30,30),ISK(30),APS(30)
      DIMENSION IOPT(34),PP(4),DEL(2)
C
      ITRCNT=0
      IACADD=0
      PRINT 2000,SV(LSV,40)
 2000 FORMAT(10X,'IN XC003  PH=',E10.3)
      DO 1 I=1,34
    1 IOPT(I)=0
      ICOUNT=0
      IOPT(1)=1
C
C
C
      IOPT(19)=1
      NS=1
      IFLAG=1
C
C
C
      IF(IPHG.NE.1) GO TO 3
      SV(LSV,40)=PHGUES
      PHLOW=PHGUES-0.5
      PHHIGH=PHGUES+0.5
      IBFLG=1
      GO TO 10
    3 CONTINUE
      CALL YEQ001(LSV,IOPT,SV(LSV,5),PP,WNES,NS)
      PRINT 2001,SV(LSV,40),DESVAL,SV(LSV,101)
 2001 FORMAT(10X,'FIRST CALL TO YEQ001 PH DESVAL RS',3E10.4)
      IF(ACDTYP.EQ.0.0) NUMAC=28
      IF(ACDTYP.EQ.1.0) NUMAC=26
      IF(ACDTYP.EQ.2.0) NUMAC=25
      ACDADD=SV(LSV,NUMAC)
    2 CONTINUE
      RSER=SV(LSV,101)-DESVAL
      IF(ABS(RSER)/DESVAL.LT.0.05) GO TO 20
      IF(RSER.LT.0.0) GO TO 5
C
      IACADD=1
      PHHIGH=SV(LSV,40)
      SV(LSV,40)=PHHIGH-1.0
      IACID=1
      GO TO 10
    5 CONTINUE
C
      IF(IACID.EQ.0) GO TO 23
      IACADD=2
      PHLOW=SV(LSV,40)
      SV(LSV,40)=PHLOW+0.5
   10 CONTINUE
      PRINT 2002,ITRCNT,PHLOW,PHHIGH,SV(LSV,40),IBFLG,SV(LSV,101)
 2002 FORMAT(10X,'ITER',I3,'PHLOW PHHIGH PH',3E10.3,'B',I3,'RS',E10.3)
      XX2=SV(LSV,NUMAC)
      XX1=1.1*XX2
      ER=REN
      ITRCNT=ITRCNT+1
      IF(ITRCNT.GT.15) GO TO 1000
C
      DO 9 I=1,10
      IF(I.EQ.1) GO TO 8
      IF(ABS(REN).LT.1.E-6) GO TO 12
      DER=(REN-ER)/(XX1-XX2)
      XX2=XX1
      ER=REN
      XX1=XX1-ER/DER
    8 SV(LSV,NUMAC)=XX1
    9 CALL YEQ001(LSV,IOPT,SV(LSV,5),PP,WNES,NS)
      PRINT 1001,SV(LSV,40)
 1001 FORMAT(//,5X,15H*****ERROR*****,//,2X,
     * 51HXC003 COULD NOT FIND AN ADDITION RATE TO ACHIEVE A ,F4.2,
     * 20H PH IN 10 ITERATIONS)
       STOP
   12 CONTINUE
      RSOUT=SV(LSV,101)
      IF(ABS(SV(LSV,101)-DESVAL)/DESVAL.LE.0.05) GO TO 20
      IF(IBFLG.EQ.1) GO TO 24
      IF(IACADD.EQ.2) GO TO 4
      PHLOW=SV(LSV,40)
      IF(RSOUT.GT.DESVAL) GO TO 2
      GO TO 6
    4 CONTINUE
      PHHIGH=SV(LSV,40)
      IF(RSOUT.LT.DESVAL) GO TO 2
    6 CONTINUE
C
C
      SV(LSV,40)=0.5*(PHHIGH+PHLOW)
      IBFLG=1
      GO TO 10
   24 CONTINUE
      RSERR=SV(LSV,101)-DESVAL
      PHINT=SV(LSV,40)
      IF(RSERR.GT.0.0) GO TO 25
      SV(LSV,40)=0.5*(PHHIGH+PHINT)
      PHLOW=PHINT
      GO TO 10
   25 CONTINUE
      SV(LSV,40)=0.5*(PHINT+PHLOW)
      PHHIGH=PHINT
      GO TO 10
 1000 PRINT 101
  101 FORMAT(10X,'COULD NOT CONVERGE ON REDES IN 10 ITERATIONS')
      STOP
   23 CONTINUE
      PRINT 102,SV(LSV,101),DESVAL
  102 FORMAT(10X,'ACID NOT REQUIRED--CACO3 RS=',E8.3,' DESVAL=',
     *  E8.3)
C
C
```

```
     20 CONTINUE
        DEL(1)=SV(LSV,NUMAC)-ACDADD
        IF(ABS(DEL(1)).LE.1.E-6) DEL(1)=0.0
  C
        LFLAG=1
        ICNT=ICNT+1
        KFLAG=0
        PHGUES=SV(LSV,40)
        IPHG=1
        RETURN
        END

@PRT,S     X.XC0004/
```

```
                                                                 DATE 113084

39U-1514*ASH(1).XC0004(12)
                COMPILER (STD=66)
                SUBROUTINE XC0004(JL)
          C
          C
          C
          C
          C
          C
          C
                DOUBLE PRECISION LABEL,IDEQP
                COMMON/CMMN/SV(25,130),IDEQP(20),ISTM(25,10),ISEQ(25),PA(20,24),
               * L(2),NL,LSRL(2),LERL(2),WV,DNAT(4),XA(4),LABEL(13),AH20
                COMMON/CNVRP/XV(10),YV(10)
                COMMON/XXLP/XLOOP
                IF(XLOOP.EQ.0.0) XLOOP=15.
                IF (ABS(YV(JL)).LT.0.015) L(JL)=1
                IF(IX.LE.2) L(JL)=0
                XV(JL)=XV(JL)+1.
                IX=XV(JL)
                PRINT 100,IX,YV(JL)
            100 FORMAT(5X,16HXC0004 LOOP NO. ,I2,5X,21H VALUE OF FUNCTION = ,E12.5
               *)
                IF(XV(JL).GT.XLOOP.AND.L(JL).NE.1) GO TO 101
                RETURN
            101 PRINT 102,XLOOP
            102 FORMAT(/,5X,27HSYSTEM DID NOT CONVERGE IN ,F8.3,11H ITERATIONS)
                IF(XLOOP.GT.1.0) L(JL)=1
                IF(XLOOP.GT.1.0) RETURN
                STOP
                END

@PRT,S    X.XEQ001/
```

```
      COMPILER (STD=66)
      SUBROUTINE XEQ001(P)
C
C
C
C
C
C
C
C
      COMMON/BD/XINERT
      COMMON/DEBUG/IPT
      COMMON/BOX/DELTA(12)
      COMMON/CIRC/ALKDES,DESVAL,QBD,KFLAG
      COMMON/ADDIT/XACID,XCAU,RHOA,RHOC
C
C
C
      DOUBLE PRECISION LABEL,IDEQP
      COMMON/CMMN/SV(25,130),IDEQP(20),ISTM(25,10),ISEQ(25),PA(20,24),
     *         L(2),NL,LSRL(2),LERL(2),WV,DNAT(4),XA(4),LABEL(13),
     *         AH2O
      COMMON/XXLP/XLOOP
      COMMON/CNVRP/XV(10),YV(10)
      COMMON/FLAG/IFLAG
      COMMON/FLAGS/KTRT,KWW,KAC,KFIX,IOUT,IUNITS,ISV
      COMMON/LCMN/XMW(100),DHF(100),ENTO(100),ACP(100),BCP(100),
     *         CCP(100),DCP(100),TMIN(100),TMAX(100),ZE(100),
     *         ALIT(100),BLIT(100),UCAP(100),SPGR(25)
      COMMON/PAGE/LINE
      COMMON/PND/DELCO2,NCHECK,PPCO2,NSFLAG
      COMMON/PRT/LIS1,LIS2,LIS3,LIS4,LIS5,LOS1,LOS2,LOS3,LOS4,LOS5
      COMMON/SOFT/FSS
      COMMON/SOLIDS/LOCSDS,CKS(30),NHY(30),ESK(30,30),ISK(30),APS(30)
      COMMON/SUMMR/RSCAS
      COMMON/AACID/ACDTYP,NUMAC
      COMMON/SFTN/CAEFF,SLAPP
      DIMENSION ACIDMW(3)
      DIMENSION P(1)
      DIMENSION COMP(13),IOPT(34),PP(4),DEL(2)
      DIMENSION DUMMY1(13),DUMMY2(13),XXMW(13)
      DIMENSION X1(13),X2(13),Y1(13),Y2(13),A(13),TEMP(13)
      REAL NAI,NSFLAG
      INTEGER OPN
      DATA IOPT/34*0/,PP/4*0.0/,COMP/13*0.0/,DEL/2*0.0/
      DATA ACIDMW/96.066,60.008,35.45/
      DATA RSLCAC,RSUCAC,RSLCAS,RSUCAS/0.5,1.0,0.9,1.0/
      DL(T)=0.99995282+0.467266E-4*(T-273.16)-0.741051E-5*(T-273.16)**2+
     *      0.410796E-7*(T-273.16)**3-0.133707E-9*(T-273.16)**4
C
C
C
C
C
      LOCSV=ISEQ(NL)
      LIS1=ISTM(LOCSV,1)
      LIS2=ISTM(LOCSV,2)
      LIS3=ISTM(LOCSV,3)
      LIS4=ISTM(LOCSV,4)
      LIS5=ISTM(LOCSV,5)
      LOS1=ISTM(LOCSV,6)
      LOS2=ISTM(LOCSV,7)
      LOS3=ISTM(LOCSV,8)
      LOS4=ISTM(LOCSV,9)
      NCNT=0
      KAVG=0
      IF(SV(LOS1,2).GT.1.5) GO TO 750
      IF(SV(LOS1,2).GT.0.5) GO TO 100
      KCOUNT=0
      KCT=0
      KKCNT=0
      LCHCK=0
C
C
C
      QBD=P(1)
      SLSOL=P(2)
      SV(18,105)=SLSOL/100.0
      ALKDES=0.0
C
C
C
      DESVAL=P(3)
      IF(KAC.EQ.1.AND.DESVAL.EQ.0.0) DESVAL=1.0
      IF(KFIX.EQ.2) FSS=P(4)
      LINE=LINE+8
      IF(LINE.LT.40) GO TO 25
      LINE=10
      PRINT 15
   15 FORMAT(1H1)
      PRINT 18,LABEL
   18 FORMAT(1H0,35X,13A6,/,1X,31HSYSTEM AND EQUIPMENT PARAMETERS)
   25 CONTINUE
      PRINT 30,LOCSV
   30 FORMAT(/,1H0,4X,24HXEQ001, EQUIPMENT NUMBER,I2)
      PRINT 32,QBD
   32 FORMAT(/,6X,26HSPECIFIED BLOWDOWN RATE = ,F10.3,4H GPM)
      PRINT 35,SLSOL
   35 FORMAT(6X,23HSOLIDS IN ASH SLURRY = ,F5.2,12H WT. PERCENT)
      IF(KAC.EQ.1) PRINT 36,DESVAL
   36 FORMAT(6X,36HDESIRED CACO3 RELATIVE SATURATION IN,
     *  20HCIRCULATING WATER = ,E7.2)
      IF(KAC.EQ.2) PRINT 40,DESVAL
   40 FORMAT(6X,42HDESIRED ALKALINITY IN CIRCULATING WATER = ,F7.2,
     *       13H PPM AS CACO3)
      IF(KAC.EQ.3) PRINT 41,DESVAL
   41 FORMAT(6X,34HDESIRED PH IN CIRCULATING WATER = ,F4.1)
      IF(KFIX.EQ.2) PRINT 45,FSS
   45 FORMAT(6X,36HINITIAL SIDESTREAM TREATMENT RATE = ,F9.2,4H GPM)
      RETURN
  100 CONTINUE
      KCOUNT=KCOUNT+1
      IF(KCOUNT.GT.1) GO TO 200
      SV(LOS3,41)=QBD*DL(SV(LOS2,5))*453.6*8.34/60.0
      SV(18,41)=SV(LIS1,32)*XMW(38)/SLSOL*(100.0-SLSOL)
C
C
C
C
C
      IGUESS=0
C
C
      QBD=SV(LOS3,41)
      SV(LOS2,41)=XMW(38)*(SV(LIS1,32))*(1.0-SV(LOS2,105))/
     *            SV(LOS2,105)
      SV(LIS2,41)=SV(LOS1,13)*18.016+SV(LOS2,41)+SV(LOS3,41)
C
```

```
C
C
   99 CONTINUE
      OPN=1
      CALL XSE008(LIS2,OPN)
      IF(IGUESS.EQ.0) QMU=SV(LIS2,41)
      IF(IPT.EQ.1) CALL XSE006(LIS1)
      IF(IPT.EQ.1) CALL XSE006(LIS2)
      DO 101 I=20,32
C
      SV(LOS3,I)=SV(LIS1,I)+SV(LIS2,I)+SV(LIS3,I)+SV(LIS4,I)
     *        +SV(LIS4,I)
  101 CONTINUE
      IF(IPT.EQ.1) CALL XSE006(LOS3)
      IF(IGUESS.EQ.0) QMU=SV(LIS2,41)
      OPN=3
      CALL XSE008(LIS2,OPN)
      SV(LOS3,31)=SV(LOS3,31)-SV(LOS1,31)
      IF(IGUESS.EQ.0) QSL=SV(LOS3,31)
       SV(LOS3,31)=QSL
      SV(LOS3,5)=SV(LOS2,5)
      IFLAG=1
      IF (NCHECK.EQ.2) NS=1
      IF (PPCO2.LE.0.0) GO TO 103
      PP(1)=PPCO2
      IOPT(2)=1
  103 CONTINUE
      IOPT(19)=1
      CALL YEQ001(LOS3,IOPT,SV(LOS3,5),PP,WNES,NS)
      IF(IPT.EQ.1) CALL XSE006(LOS3)
      IF(NSFLAG.EQ.0.0) GO TO 3010
      IF(NSFLAG.EQ.1.0) GO TO 3010
      DO 3004 I=1,12
      SV(25,I+105)=NSFLAG*SV(LOS3,I+105)
      SV(LOS3,I+105)=SV(LOS3,I+105)-SV(25,I+105)
 3004 CONTINUE
      OPN=3
      CALL XSE008(LOS3,OPN)
      NS=1
      CALL YEQ001(LOS3,IOPT,SV(LOS3,5),PP,WNES,NS)
      NS=0
      DO 3007 I=1,12
      SV(LOS3,I+105)=SV(25,I+105)
      SV(25,I+105)=0.0
 3007 CONTINUE
      CALL XSE008(LOS3,OPN)
 3010 CONTINUE
      NS=0
      IOPT(2)=0
      PP(4)=0.0
      DO 105 I=1,65
      SV(LOS2,I+37)=SV(LOS3,I+37)
  105 CONTINUE
      SV(LOS2,41)=SV(LOS3,41)-QBD-SV(LOS4,41)
      SV(LOS3,41)=QBD
      DO 110 I=1,13
      SV(LOS2,I+105)=SV(LOS3,I+105)
      SV(LOS3,I+105)=0.0
  110 CONTINUE
      IF(IPT.EQ.1) CALL XSE006(LOS2)
      IF(IPT.EQ.1) CALL XSE006(LOS3)
C
C
C
      REC=SV(LIS1,32)*XMW(38)*((100.D-SLSOL)/SLSOL)-SV(LIS2,41)-
     *     SV(LIS3,41)
      IF(REC.LT.0.D) REC=0.0
      SV(11,41)=REC+SV(LOS3,41)
  111 CONTINUE
      IF (KTRT.NE.2.AND.KTRT.NE.5.AND.KTRT.NE.6.AND.KTRT.NE.8)
     *     GO TO 115
C
C
C
C
C
C
      KFLAG=0
      LFLAG=0
      SV(LOS3,41)=SV(11,41)
      OPN=3
      CALL XSE008(LOS3,OPN)
      IF(KAC.EQ.1) CALL XC0003(LOS3,DEL,LFLAG)
      IF(KAC.EQ.2) CALL XC0001(LOS3,DEL,LFLAG)
      IF(KAC.EQ.3) CALL XC0002(LOS3,DEL,LFLAG)
      SV(LIS3,NUMAC)=DEL(1)
      C
      C
            IF(ACDTYP.EQ.0.0) IIACID=1
            IF(ACDTYP.EQ.1.0) IIACID=2
            IF(ACDTYP.EQ.2.0) IIACID=3
            SV(LIS3,41)=SV(LIS3,NUMAC)*ACIDMW(IIACID)/XACID*(1.0-XACID)
            SV(LIS3,31)=SV(LIS3,41)/18.01556
      C
      C
            IF(ACDTYP.EQ.0.0) SV(3,86)=SV(LIS3,28)/(SV(LIS3,41)/1000.0)
            IF(ACDTYP.EQ.1.0) SV(3,84)=SV(LIS3,26)/(SV(LIS3,41)/1000.0)
            IF(ACDTYP.EQ.2.0) SV(3,83)=SV(LIS3,25)/(SV(LIS3,41)/1000.0)
            SV(LOS3,41)=QBD
             IF (KCOUNT.GE.2) GO TO 115
            SAVEMU=SV(LIS2,41)
            SV(LIS2,41)=QMU-SV(LIS3,41)
      C
      C
      C
      C
        115 CONTINUE
      C
      C
      C
            IF(KFIX.EQ.2) SV(13,41)=FSS*DL(SV(LOS3,5))*453.6*8.34/60.
            IF(SV(13,41).LE.0.0) SV(13,41)=0.2*SV(11,41)
            SV(13,5)=SV(LOS3,5)
            OPN=3
            CALL XSE008(LIS2,OPN)
            CALL XSE008(LIS3,OPN)
            CALL XSE008(LOS2,OPN)
            CALL XSE008(LOS3,OPN)
            IF(KCOUNT.GE.2) GO TO 657
            DO 150 I=1,13
            COMP(I)=SV(LOS3,I+19)
            IF(QBD.LE.0.0) COMP(I)=SV(LOS2,I+19)
        150 CONTINUE
            IATOM=0
            IVCTOR=0
      C
            IF(IPT.EQ.1) CALL XSE006(LIS1)
            IF(IPT.EQ.1) CALL XSE006(LIS2)
            IF(IPT.EQ.1) CALL XSE006(LIS3)
      IF(IPT.EQ.1) CALL XSE006(LOS1)
      IF(IPT.EQ.1) CALL XSE006(LOS2)
      IF(IPT.EQ.1) CALL XSE006(LOS3)
      CALL XSE002
      IF(IPT.EQ.1.AND.XLOOP.EQ.1.0) STOP
      RETURN
  200 CONTINUE
C
C
C
C
      KAVG=1
      QMU=SV(LIS2,41)
      SV(LIS2,41)=SV(LOS1,31)*XMW(3)+SV(LOS2,41)+SV(LOS3,41)+SV(LOS4,41)
     *             -SV(LIS1,41)-SV(LIS3,41)-SV(LIS4,41)-SV(LIS5,41)
      IF(SV(LIS2,41).LT.0.0) SV(LIS2,41)=0.0
      OPN=1
      CALL XSE008(LIS2,OPN)
      IOPT(19)=1
      NS=1
      IFLAG=1
      CALL YEQU01(LIS2,IOPT,SV(LIS2,5),PP,WNES,NS)
      NS=0
      SV(LIS2,32)=SV(LIS2,32)*SV(LIS2,31)/QMU
      SV(LIS2,118)=SV(LIS2,32)
      QMU=SV(LIS2,41)
      DO 202 I=1,65
      SV(LOS3,I+37)=SV(LOS2,I+37)
  202 CONTINUE
      SV(LOS3,41)=QBD
      OPN=3
      CALL XSE008(LOS3,OPN)
      NFLAG=0
      IF(KCOUNT.GE.2) GO TO 111
C
C
C
  657 CONTINUE
C
C
C
C
C
```

```
C
      YV(1)=0.0
      DO 660 I=1,13
      IF(SV(LOS3,I+19).LE.0.0) GO TO 660
      YV(1)=YV(1)+ABS(COMP(I)-SV(LOS3,I+19))/SV(LOS3,I+19)
      COMP(I)=SV(LOS3,I+19)
  660 CONTINUE
      XINERT=SV(LOS3,32)/SV(LOS3,41)
      KAVG=0
      IATOM=0
      IVCTOR=0
      CALL XSE003 (IATOM,IVCTOR)
      CALL XSE002
      RETURN
C
C
C
  750 CONTINUE
      LINE=LINE+11
      IF(LINE.LT.40) GO TO 760
      LINE=13
      PRINT 15
      PRINT 755,LABEL
  755 FORMAT(1H0,35X,13A6,/,1X,32HCALCULATED SYSTEM AND EQUIPMENT ,
     *       10HPARAMETERS)
  760 CONTINUE
      PRINT 30,LOCSV
      GPMMW=SV(LIS1,31)*XMW(3)/DL(SV(LIS1,5))*0.01585
      IF(SV(LIS3,31).GT.0.0) GPMAC=SV(LIS3,31)*XMW(3)/DL(SV(LIS3,5))*
     *                             0.01585
      IF(SV(LIS5,31).GT.0.0) GPMWW=SV(LIS5,31)*XMW(3)/DL(SV(LIS5,5))*
     *                             0.01585
      GPMEV=SV(LOS1,31)*XMW(3)/DL(SV(LOS1,5))*0.01585
      GPMPS=SV(LOS2,31)*XMW(3)/DL(SV(LOS2,5))*0.01585
      IF(SV(LOS3,31).GT.0.0) GPMBD=SV(LOS3,31)*XMW(3)/DL(SV(LOS3,5))*
     *                             0.01585
      IF(SV(LOS4,31).GT.0.0) GPMSS=SV(LOS4,31)*XMW(3)/DL(SV(LOS4,5))*
     *                             0.01585
      TOTIN=GPMMW+GPMAC+GPMWW
      TOTOUT=GPMEV+GPMPS+GPMBD+GPMSS
      PRINT 780
  780 FORMAT(/,7X,28HINLET LIQUID FLOWRATES (GPM),6X,
     *       29HOUTLET LIQUID1FLOWRATES (GPM),/)
```

```
      PRINT 782,GPMMW,GPMEV
  782 FORMAT(6X,24HMAKEUP WATER          = ,F7.1,9X,
     *       19HEVAPORATION  3   = ,F7.1)
      PRINT 784,GPMAC,GPMPS
  784 FORMAT(6X,24HACID/CAUSTIC          = ,F7.1,9X,
     *       19HPOND SLUDGE      = ,F7.1)
      PRINT 786,GPMWW,GPMBD
  786 FORMAT(6X,24HADDITIONAL WASTEWATER = ,F7.1,9X,
     *       19HBLOWDOWN         = ,F7.1)
      PRINT 788,GPMSS
  788 FORMAT(46X,19HSIDESTREAM WASTE = ,F7.1)
      PRINT 790
  790 FORMAT(37X,7H-------,33X,7H-------)
      PRINT 800,TOTIN,TOTOUT
  800 FORMAT(36X,F8.1,32X,F8.1)
      RETURN
      END

@PRT,S    X.XEQ002/
```

```
      COMPILER (STD=66)
      SUBROUTINE XEQ002(P)
C
C
C
C
      COMMON/ASHCOM/ASHFLO,XASH(7)
C
C
C
      DOUBLE PRECISION LABEL,IDEQP
      COMMON/CMMN/SV(25,130),IDEQP(20),ISTM(25,10),ISEQ(25),PA(20,24),
     *           L(2),NL,LSRL(2),LERL(2),WV,DNAT(4),XA(4),LABEL(13),
     *           AH2O
      COMMON/LCMN/XMW(100),DHF(100),ENTO(100),ACP(100),BCP(100),CCP(100)
     *          ,DCP(100),TMIN(100),TMAX(100),ZE(100),ALIT(100),
     *           BLIT(100),UCAP(100),SPGR(25)
      COMMON/PAGE/LINE
      DIMENSION P(1)
C
      LOCSL=ISEQ(NL)
      LOS=ISTM(LOCSL,6)
      IF(SV(LOS,2).GT.0.5)  RETURN
C
      DO 1 I=1,7
    1 XASH(I)=P(I+1)
      SV(LOS,5)=273.16+(P(1)-32.)/1.8
      ASHFLO=P(9)
      LINE=LINE+9
      IF(LINE.LT.43) GO TO 4
      LINE=9
      WRITE(6,2)
    2 FORMAT(1H1)
      WRITE(6,3) LABEL
    3 FORMAT(1H0,35X,13A6,/,1X,31HSYSTEM AND EQUIPMENT PARAMETERS)
    4 WRITE(6,5) LOCSL, ASHFLO,P(1)
    5 FORMAT(//,4X,24HXEQ002, EQUIPMENT NUMBER,I3,/,6X,13HASH FLOW RATE,
     *       3H = ,E11.4,7H LB/MIN,/,6X,14HTEMPERATURE = ,F5.1,
     *       6H DEG F)
      ASHFLO=ASHFLO*453.5924/60.
      SV(LOS,20)=XASH(1)*ASHFLO/XMW(83)
      SV(LOS,21)=XASH(2)*ASHFLO/XMW(84)
      SV(LOS,22)=XASH(3)*ASHFLO/XMW(85)
      SV(LOS,24)=XASH(4)*ASHFLO/XMW(87)
      SV(LOS,25)=XASH(5)*ASHFLO/XMW(88)
      SV(LOS,28)=XASH(6)*ASHFLO/XMW(91)
      SV(LOS,29)=P(10)*ASHFLO/XMW(35)
      SV(LOS,32)=(ASHFLO-SV(LOS,20)-SV(LOS,21)-SV(LOS,22)-SV(LOS,24)
     *           -SV(LOS,25)-SV(LOS,28)-SV(LOS,29))/XMW(38)
      SV(LOS,118)=SV(LOS,32)
      DO 8 I=1,7
    8 XASH(I)=100.*XASH(I)
      WRITE(6,9) (XASH(I),XASH(I+3),I=1,3),XASH(7)
     *  ,P(10)
    9 FORMAT(/,8X,7HSPECIES,10X,5HWT. %,8X,7HSPECIES,10X,5HWT. %,/,
     1 8X,4HCA++,11X,F9.3,6X,2HK+,13X,F9.3,/,
     2 8X,4HMG++,11X,F9.3,6X,3HCL-,12X,F9.3,/,
     3 8X,3HNA+,12X,F9.3,6X,5HSO4--,10X,F9.3,/,
     4 8X,5HINERT,10X,F9.3,6X,4HSIO2,11X,2PF9.3)
C
      RETURN
      END
```

```
@PRT,S    X.XEQ003/
```

```
390-1514*ASH(1).XEQ003(51)
      COMPILER (STD=66)
      SUBROUTINE XEQ003(P)
      COMMON/ADDIT/XACID,XCAU,RHOA,RHOC
C
C
C
      DOUBLE PRECISION LABEL,IDEGP
      COMMON/CMMN/SV(25,130),IDEQP(20),ISTM(25,10),ISEQ(25),PA(20,24),
     *           L(2),NL,LSRL(2),LERL(2),WV,DNAT(4),XA(4),LABEL(13),
     *           AH20
      COMMON/FLAGS/KTRT,KWW,KAC,KFIX,IOUT,IUNITS,ISV
      COMMON/LCMN/XMW(100),DHF(100),ENTO(100),ACP(100),BCP(100),CCP(100)
     *          ,DCP(100),TMIN(100),TMAX(100),ZE(100),ALIT(100),
     *           BLIT(100),UCAP(100),SPGR(25)
      COMMON/PAGE/LINE
      COMMON/AACID/ACDTYP,NUMAC
      COMMON/SSCHEM/XLIMSS(4),XSODSS(3),XMGSS(4),XCAUSS(3)
      DIMENSION P(24),WS(2),WL(3),WC(4),WM(3)
      LOCSV=ISEQ(NL)
      LOS=ISTM(LOCSV,6)
      IF(SV(LOS,2).GT.1.5) RETURN
      IF(SV(LOS,2).GT.0.5) GO TO 60
C
C
C
      DO 2 I=1,3
      IF(I.EQ.3) GO TO 1
      XSODSS(I)=P(I+5)
      WS(I)=XSODSS(I)*100.
 1    XLIMSS(I)=P(I+1)
      WL(I)=XLIMSS(I)*100.
      XCAUSS(I)=P(I+13)
      WC(I+1)=XCAUSS(I)*100.
      XMGSS(I)=P(I+8)
 2    WM(I)=XMGSS(I)*100.
      XCAUSS(1)=XCAUSS(1)+P(13)
      IF(XCAUSS(1).LE.0.) XCAUSS(1)=1.
      WC(1)=P(13)*100.
C
C
C
      XLIMSS(4)=P(1)
      XSODSS(3)=P(5)
      XMGSS(4)=P(8)
      QCAU=P(12)
      XCAU=P(17)*0.01
      QACID=P(18)
      ACDTYP=P(20)
      XACID=P(19)*.01
      GO TO 200
   60 CONTINUE
      IF(XCAU.LE.0.) XCAU=0.5
      IF(XACID.LE.0.) XACID=0.98
      IF(LOS.EQ.3) GO TO 100
      IF(KFIX.GT.1) GO TO 3
      A=XLIMSS(4)+XSODSS(3)+XMGSS(4)
      IF(A.GT.0.0) GO TO 10
 3    SV(LOS,106)=(XLIMSS(4)*XLIMSS(1)+XMGSS(4)*XMGSS(2))*453.6/(60.*
     *  XMW(26))
      SV(LOS,111)=(XLIMSS(4)*XLIMSS(2)+XMGSS(4)*XMGSS(1))*453.6/(60.*
     *    XMW(31))
      SV(LOS,117)=XSODSS(3)*XSODSS(1)*453.6/(60.*XMW(37))
      SV(LOS,118)=XLIMSS(4)*XLIMSS(3)+XMGSS(4)*XMGSS(3)+
     *               XSODSS(3)*XSODSS(2)
      GO TO 140
  100 CONTINUE
      IF(XCAU.LE.0.34) RHOC=1.0965*XCAU+0.9992
      IF(XCAU.GT.0.34) RHOC=0.9649*XCAU+1.0434
      IF(XACID.LE.0.5) RHOA=.775*XACID+.991
      IF(XACID.GT.0.5.AND.XACID.LE..9) RHOA=1.05*XACID+.865
      IF(XACID.GT..9) RHOA=1.83
      SV(LOS,41)=(QACID*(1.-XACID)*RHOA+QCAU*(1.-XCAU)*RHOC)*8.34*
     *     453.6/3600.
      IF(SV(LOS,41).LE.0.0) GO TO 140
      IF(QACID.LE.0.0) GO TO 120
      SV(LOS,42)=2.*1000.*XACID/(98.*(1.-XACID))
      SV(LOS,86)=0.5*SV(LOS,42)
  120 CONTINUE
      IF(QCAU.LE.0.0) GO TO 140
      SV(LOS,43)=1000.*XCAU*XCAUSS(1)/(40.*(1.-XCAU))
      SV(LOS,80)=1000.*XCAU*(XCAUSS(1)+XCAUSS(2))/(40.*(1.-XCAU))
      SV(LOS,83)=1000.*XCAU*XCAUSS(2)/(40.*(1.-XCAU))
      SV(LOS,118)=(SV(LOS,118)+XCAU*XCAUSS(3)*QCAU*RHOC*8.34/60.)*453.6/
     * (60.*XMW(38))
  140 CONTINUE
```

```
      SV(LOS,5)=298.
      SV(LOS,6)=1.
      K1=3
      CALL XSE008(LOS,K1)
      RETURN
  200 CONTINUE
      LINE=LINE+19
      IF(LINE.LT.43) GO TO 5
      LINE=21
      WRITE(6,4) LABEL
    4 FORMAT(1H0,35X,13A6,/,1X,31HSYSTEM AND EQUIPMENT PARAMETERS)
5     WRITE(6,6) LOCSV
    6 FORMAT(/,5X,25HXEQ003, EQUIPMENT NUMBER ,I2,/)
      WRITE(6,7) XLIMSS(4),XSODSS(3),XMGSS(4)
7     FORMAT(8X,25HLIME ADDITION RATE      = ,1PE10.4,7H LB/MIN,/,
     *        8X,25HSODA ASH ADDITION RATE = ,1PE10.4,7H LB/MIN,/,
     *        8X,25HMG(OH)2 ADDITION RATE  = ,1PE10.4,7H LB/MIN,/)
      WRITE(6,8) (WL(I),WS(I),WM(I),WC(I),I=1,2),WL(3),WM(3),WC(3),WC(4)
8     FORMAT(14X,4HLIME,17X,8HSODA ASH,15X,7HMG(OH)2,11X,19HCAUSTIC (DRY
     *BASIS),/,7X,4(7HSPECIES,6X,5HWT. %,5X),/,7X,4(7H*******,6X,5H*****
     2,5X),/,7X,7HCA(OH)2,6X,F5.1,5X,7HNA2CO3 ,6X,F5.1,5X,7HMG(OH)2,6X,
     3F5.1,5X,7HNAOH   ,6X,F5.1,/,7X,7HMG(OH)2,6X,F5.1,5X,7HINERT  ,6X,
     4F5.1,5X,7HCA(OH)2,6X,F5.1,5X,7HNA2O   ,6X,F5.1,/,7X,7HINERT  ,6X,
     5F5.1,28X,7HINERT  ,6X,F5.1,5X,7HNACL   ,6X,F5.1,/,76X,7HINERT  ,
     6 6X,F5.1)
      XACID=XACID*100.
      XCAU=XCAU*100.
      WRITE(6,9) QACID,XACID,QCAU,XCAU
9     FORMAT(/,8X,21HSULFURIC ACID RATE = ,1PE10.4,7H GAL/HR,/,10X,  14H
     1COMPOSITION = ,0PF4.1,6H WT. %,/,8X,21HCAUSTIC SODA RATE  = ,1PE10
     2.4,7H GAL/HR,/,10X ,14HCOMPOSITION = ,0PF4.1,6H WT. %)
      XACID=XACID*0.01
      XCAU=XCAU*0.01
      RETURN
10    WRITE(6,11) LOCSV
11    FORMAT(//,5X,38H***** FATAL ERROR IN XEQ003, EQPT. NO.,I2,6H *****
     *,//,3X,54HTHE USER HAS NOT FIXED THE SOFTENER FEED RATE, BUT HAS,/
     *,3X,53HFIXED THE CHEMICAL ADDITION RATES.  THIS COMBINATION ,/,3X,
     *52HIS INCONSISTENT WITH CALCULATIONAL PROCEDURES IN THE,/,3X,6HMOD
     *EL.)
      STOP
      END
```

DATE 113084

@PRT,S X.XEQ004/

```
390-1514*ASH(1).XEQ004(43)
      COMPILER (STD=66)
      SUBROUTINE XEQ004(P)
      COMMON/FLAG/IFLAG
      COMMON/PAGE/LINE
      COMMON/RESEN/REN
C
C
C
      DOUBLE PRECISION LABEL,IDEQP
      COMMON/CMMN/SV(25,130),IDEQP(20),ISTM(25,10),ISEQ(25),PA(20,24),
     *          L(2),NL,LSRL(2),LERL(2),WV,DNAT(4),XA(4),LABEL(13),
     *          AH2O
      COMMON/LCMN/XMW(100),DHF(100),ENTO(100),ACP(100),BCP(100),
     *          CCP(100),DCP(100),TMIN(100),TMAX(100),ZE(100),
     *          ALIT(100),BLIT(100),UCAP(100),SPGR(25)
      COMMON/WTRIN/CONC(12),WWCONC(12)
      DIMENSION IOPT(34),XX(2),ER(2),YMW(11)
      DIMENSION P(1)
      DATA YMW/40.1,24.3,23.,18.,39.1,35.5,100.1,62.,96.,60.1,95./
      LOCSV=ISEQ(NL)
      LOS=ISTM(LOCSV,6)
      KEY=SV(LOS,2)
      IF(KEY.GT.0.5) RETURN
      T=P(1)
      SV(LOS,5)=(P(1)-32.)/1.8+273.16
      SV(LOS,6)=1.
      CONCT=0.
      DO 10 I=1,12
      CONC(I) = P(I+1)
   10 CONCT=CONCT+CONC(I)
      CONCT=CONCT/1000000.
      FACTOR=1./(1.-CONCT)/1000.
      DO 20 I=1,11
   20 SV(LOS,I+77)=CONC(I)*FACTOR/XMW(I+82)
      SV(LOS,87)=CONC(10)*FACTOR/XMW(35)
      SV(LOS,45) = CONC(7)*FACTOR/50.04
      PH=P(14)
      ION=P(15)+.01
      SV(LOS,40)=PH
      IF(ION.LE.0) ION=3
      SV(LOS,41)=1000.*(1.-CONCT)
      K1=1
      CALL XSE008(LOS,K1)
      NS=1
      IOPT(1)=1
      IOPT(19) = 1
      IFLAG=1
   25 CALL YEQ001(LOS,IOPT,SV(LOS,5),PP,WNES,NS)
      XX(2)=SV(LOS,ION+19)
      DO 50 I=1,10
      IF(ABS(REN).LT.1.E-6) GO TO 55
      IF(I.NE.1) GO TO 30
      XX(1)=1.05*XX(2)
      ER(2)=REN
      GO TO 35
   30 CONTINUE
      DER=(ER(1)-ER(2))/(XX(1)-XX(2))
      XX(2) = XX(1)
      ER(2) = ER(1)
      XX(1)=XX(1)-ER(1)*DER/(DER*DER)
   35 CONTINUE
      SV(LOS,ION+19)=XX(1)
      IF(XX(1).GT.0) GO TO 40
      PRINT 100
      STOP
   40 CALL YEQ001(LOS,IOPT,SV(LOS,5),PP,WNES,NS)
   50 ER(1) = REN
   55 CONTINUE
      XF=SV(LOS,ION+19)*1000000.*YMW(ION)*(1.-CONCT)/SV(LOS,41)
      TOTALK=2.*(SV(LOS,52)+SV(LOS,57)+SV(LOS,61)+SV(LOS,84))+SV(LOS,43)
     *        +SV(LOS,45)+SV(LOS,50)+SV(LOS,51)+SV(LOS,55)+SV(LOS,56)+
     *        SV(LOS,59)+SV(LOS,60)
     *-SV(LOS,42)
      TOTALK=TOTALK*1000.*50.04*(1.-CONCT)
      TEST=(TOTALK-CONC(7))/CONC(7)
      IF(ABS(TEST).LE.0.01) GO TO 60
      SV(LOS,26)=SV(LOS,26)*CONC(7)/TOTALK
      GO TO 25
   60 CONTINUE
      LINE=LINE+12
      IF(LINE.LT.37) GO TO 65
      LINE=10
      PRINT 101,LABEL
   65 PRINT 102,ISEQ(NL)
      PRINT 103
      PRINT 104
      PRINT 105,CONC(1),CONC(7)
      PRINT 106,CONC(2),CONC(8)
      PRINT 107,CONC(3),CONC(9)
      PRINT 108,CONC(4),CONC(10)
      PRINT 109,CONC(5),CONC(11)
      PRINT 110,CONC(6),CONC(12)
      CONC(ION)=XF
      PRINT 111,ION,XF
      PRINT 112,T,PH
  100 FORMAT(53HTHE ION CHOSEN TO MINIMIZE ION IMBALANCE IS TOO SMALL,/,
     *       15HTRY ANOTHER ONE)
  101 FORMAT(1H1,13A6,/,1X,10HINPUT DATA)
  102 FORMAT(/,5X,18HXEQ004, EQPT. NO. ,I2)
  103 FORMAT(6X,23HMAKEUP WATER INPUT DATA)
  104 FORMAT(8X,3HION,8X,7HSPECIES,8X,18HCONCENTRATION, PPM,5X,3HION,10X
     *,7HSPECIES,10X,18HCONCENTRATION, PPM)
  105 FORMAT(9X,1H1,4X,15HCALCIUM (AS CA),8X,F8.1,11X,1H7,4X,21HALKALINI
     *TY (AS CACO3),8X,F8.1)
  106 FORMAT(9X,1H2,4X,17HMAGNESIUM (AS MG),6X,F8.1,11X,1H8,4X,16HNITRAT
     *E (AS NO3),13X,F8.1)
  107 FORMAT(9X,1H3,4X,14HSODIUM (AS NA),9X,F8.1,11X,1H9,4X,16HSULFATE (
     *AS SO4),13X,F8.1)
  108 FORMAT(9X,1H4,4X,16HAMMONIA (AS NH4),7X,F8.1,11X,2H10,3X,
     *       16HSILICA (AS SIO2),13X,F8.1)
  109 FORMAT(9X,1H5,4X,16HPOTASSIUM (AS K),7X,F8.1,11X,2H11,3X,
     *       18HPHOSPHATE (AS PO4),11X,F8.1)
  110 FORMAT(9X,1H6,4X,16HCHLORIDE (AS CL),7X,F8.1,11X,2H12,3X,
     *       11HSUS. SOLIDS,18X,F8.1)
  111 FORMAT(9X,8HION NO. ,I2,13H ADJUSTED TO ,F8.1,30H PPM TO MINIMIZE
     *ION IMBALANCE)
  112 FORMAT(9X,14HTEMPERATURE = ,F5.1,7H DEG. F,/,9X,5HPH = ,F5.2)
      RETURN
      END

@PRT,S     X.XEQ005/
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```
      COMPILER (STD=66)
      SUBROUTINE XEQ005(P)
C
C
C
C
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C
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C
C
      DOUBLE PRECISION LABEL,IDEQP
      COMMON/CMMN/SV(25,130),IDEQP(20),ISTM(25,10),ISEQ(25),PA(20,24),
     *            L(2),NL,LSRL(2),LERL(2),WV,DNAT(4),XA(4),LABEL(13),
     *            AH20
      COMMON/FLAG/IFLAG
      COMMON/FLAGS/KTRT,KWW,KAC,KFIX,IOUT,IUNITS,ISV
      COMMON/DEBUG/IPT
      COMMON/PAGE/LINE
      COMMON/PND/DELCO2,NCHECK,PPCO2,NSFLAG
      COMMON/PPT/IRATE
      COMMON/RATE/XNI(30),PB(30),RK(30),RM(30),VRK(30)
      DIMENSION P(1)
      DIMENSION IOPT(34),PP(10),RATES(13)
      INTEGER OPN
      REAL NEVAP,NSFLAG
      DATA IOPT/34*0/,PP/10*0.0/
      DATA RATES/13*0.0/
      DL(T)=0.99995282+0.467266E-4*(T-273.16)-0.741051E-5*(T-273.16)**2
     *      +0.410796E-7*(T-273.16)**3-0.133707E-9*(T-273.16)**4
C
C
C
C
C
C
C
C
      LOCSV=ISEQ(NL)
      LIS1=ISTM(LOCSV,1)
      LIS2=ISTM(LOCSV,2)
      LOS1=ISTM(LOCSV,6)
      LOS2=ISTM(LOCSV,7)
      LOS3=ISTM(LOCSV,8)
      IF(SV(LOS1,2).GT.1.5) GO TO 250
      IF(SV(LOS1,2).GT.0.5) GO TO 100
C
C
C
      NEVAP=P(1)
      PNDSOL=P(2)
       SV(LOS2,105)=PNDSOL/100.0
      PNDSA=P(3)
      PNDDP=P(4)
      RXNVOL=PNDSA*PNDDP*43560.0*28317.0
      PNDWT=P(5)
      SV(LOS2,5)=(PNDWT-32.0)/1.8+273.16
      SV(LOS1,5)=SV(LOS2,5)
      SV(LOS3,5)=SV(LOS2,5)
      SV(LOS1,13)=NEVAP*PNDSA*3.26*DL(SV(LOS3,5))/18.016
      SV(LOS1,31)=SV(LOS1,13)
      SV(LOS1,10)=SV(LOS1,13)
      PPCO2=0.0
      PPCO2=P(6)
C
C
C
C
C
C
      NCHECK=P(7)+1
      IF(NCHECK.LE.0) NCHECK=1
      NSFLAG=P(8)
      IF(NSFLAG.GT.1.0) NSFLAG=1.0
C
C
C
      LINE=LINE+7
      IF(LINE.LT.40) GO TO 25
      LINE=9
      PRINT 10
   10 FORMAT(1H1)
      PRINT 15,LABEL
   15 FORMAT(1H0,35X,13A6,/,1X,31HSYSTEM AND EQUIPMENT PARAMETERS)
   25 CONTINUE
      PRINT 30,LOCSV
   30 FORMAT(/,1H0,4X,24HXEQ005, EQUIPMENT NUMBER,I2)
      PRINT 40,NEVAP,PNDSOL,PNDSA,PNDDP,PNDWT
   40 FORMAT(/,6X,25HNET ANNUAL EVAPORATION = ,F5.1,7H INCHES,/,6X,
     *         43HWT. PERCENT SOLIDS IN POND BOTTOM SLUDGE = ,F5.1,/,6X,
     *         20HPOND SURFACE AREA = ,F6.2,6H ACRES,/,6X,
     *         25HAPPROXIMATE POND DEPTH = ,F5.1,3H FT,/,6X,
     *         25HPOND WATER TEMPERATURE = ,F5.1,6H DEG F)
      IF(PPCO2.GT.0.0) PRINT 50,PPCO2
   50 FORMAT(6X,38HUSER SPECIFIED CO2 PARTIAL PRESSURE = ,F7.5,4H ATM)
      IF(NSFLAG.GT.0.0) GO TO 75
      IF(NCHECK.EQ.1) PRINT 55
   55 FORMAT(6X,38HPOND WATER AT LIQUID/SOLID EQUILIBRIUM)
      IF(NCHECK.EQ.2) PRINT 60
   60 FORMAT(6X,35HNO SOLIDS FORMATION ALLOWED IN POND)
      IF(NCHECK.EQ.3) PRINT 65
   65 FORMAT(6X,52HRATE DATA USED TO DETERMINE SOLIDS FORMATION IN POND)
      RETURN
   75 CONTINUE
      NCHECK=1
      PERCNT=100.0*NSFLAG
      PRINT 80,PERCNT
   80 FORMAT(6X,31HPOND COMPOSITION CALCULATED AS ,F4.1,
     *         11H % APPROACH,/,8X,27HTO SOLID/LIQUID EQUILIBRIUM)
      RETURN
C
C
C
C
  100 CONTINUE
      SV(LOS2,5)=(PNDWT-32.)/1.8+273.16
      SV(LOS3,5)=SV(LOS2,5)
      SV(LOS1,5) = SV(LOS2,5)
      SV(LOS3,41)=SV(LIS1,41)+SV(LIS2,41)-SV(LOS1,31)*18.016
      IF(SV(LOS3,41).GT.0.0) GO TO 103
      EV=SV(LOS1,31)*18.016
      PRINT 102,SV(LIS1,41),SV(LIS2,41),EV,SV(LOS3,41)
  102 FORMAT(1H0,5X,31H***** FATAL ERROR IN XE05 *****,/,
     *        5X,27HNEGATIVE OVERFLOW FROM POND,/,8X,
     *        29HFLY ASH WATER TO POND       = ,E10.4,10H GRAMS/SEC,/,8X,
     *        29HWASTEWATER TO POND          = ,E10.4,10H GRAMS/SEC,/,8X,
     *        29HWATER EVAPORATED FROM POND = ,E10.4,10H GRAMS/SEC)
```

```
      STOP
  103 CONTINUE
      OPN=1
      CALL XSE008(LIS1,OPN)
C
      DO 105 I=1,13
      SV(LOS3,I+19)=SV(LIS1,I+19)+SV(LIS2,I+19)
  105 CONTINUE
C
      DO 106 I=1,12
  106 SV(LOS2,I+105)=SV(LIS1,I+105)
      SV(LOS2,118)=0.0
      SV(LOS3,32)=SV(LIS1,118)+SV(LIS2,118)
      SV(LOS3,118)=SV(LOS3,32)
      SV(LOS3,31)=SV(LOS3,31)-SV(LOS1,31)
      IF(PPCO2.LE.0.0) GO TO 110
      CO2SAV=SV(LOS3,26)
      PP(1)=PPCO2
      IOPT(2)=1
  110 CONTINUE
      IFLAG=1
      IOPT(19)=1
      IF (NCHECK.EQ.2) NS=1
      IF(NCHECK.LE.2) GO TO 115
      IRATE=1
      DO 113 I=1,12
      VRK(I)=RATES(I)*RXNVOL*7.5
      IF(VRK(I).GT.0.0) IOPT(I+20)=1
  113 CONTINUE
  115 CONTINUE
      CALL YEQ001(LOS3,IOPT,SV(LOS3,5),PP,WNES,NS)
      OPN=3
      CALL XSE008(LOS3,OPN)
      IF(NSFLAG.EQ.0.0) GO TO 119
      IF(NSFLAG.EQ.1.0) GO TO 119
      DO 117 I=1,12
      SV(25,I+105)=NSFLAG*SV(LOS3,I+105)
      SV(LOS3,I+105)=SV(LOS3,I+105)-SV(25,I+105)
  117 CONTINUE
      OPN=3
      CALL XSE008(LOS3,OPN)
      NS=1
      CALL YEQ001(LOS3,IOPT,SV(LOS3,5),PP,WNES,NS)
      NS=0
      DO 118 I=1,12
      SV(LOS3,I+105)=SV(25,I+105)
      SV(25,I+105)=0.0
  118 CONTINUE
      CALL XSEU08(LOS3,OPN)
  119 CONTINUE
      DELCO2=0.0
      IF(PPCO2.GT.0.0) DELCO2=SV(LOS3,26)-CO2SAV
      SV(LOS1,26)=SV(LIS1,26)+SV(LIS2,26)-SV(LOS3,26)
      SV(LOS1,14)=SV(LOS1,26)
      IF(SV(LOS3,105).LT.SV(LOS2,105)) GO TO 130
      EQSOL=SV(LOS3,105)*100.0
      PRINT 120,PNDSOL,EQSOL
  120 FORMAT(1H1,///,15X,31H***** FATAL ERROR IN XEQ5 *****,/,5X,
     *       41HTHE USER HAS SPECIFIED A POND BOTTOMS OF ,F5.1,
     *       18H WT PERCENT SOLIDS,/,5X,28HTHIS VALUE IS LESS THAN THE ,
     *       F5.1,49H WT PERCENT SOLIDS AT EQUILIBRIUM POND CONDITIONS)
      STOP
  130 CONTINUE
      IW=5
      WTLOS3=XSEU09(LOS3,IW)
      WTLOS2=XSEU09(LOS2,IW)
C
C
      WSLUDG=(WTLOS3+WTLOS2)/SV(LOS2,105)
      SV(LOS2,41)=WSLUDG-WTLOS3-WTLOS2
      SV(LOS3,41)=SV(LOS3,41)-SV(LOS2,41)
      DO 150 I=1,47
      II=I+41
      SV(LOS2,II)=SV(LOS3,II)
  150 CONTINUE
      DO 160 I=1,13
      II=I+105
      SV(LOS2,II)=SV(LOS3,II)+SV(LOS2,II)
      SV(LOS3,II)=0.0
  160 CONTINUE
      DO 170 I=1,3
      II=I+37
      JJ=I+99
      SV(LOS2,II)=SV(LOS3,II)
      SV(LOS2,JJ)=SV(LOS3,JJ)
  170 CONTINUE
```

```
      SV(LOS2,6)=SV(LOS3,6)
      OPN=3
      CALL XSE008(LOS2,OPN)
      CALL XSE008(LOS3,OPN)
      IRATE=0
      DO 180 I=1,12
      VRK(I)=0.0
      IOPT(I+20)=0
  180 CONTINUE
      NS=0
      K2=0
      K3=0
      CALL XSE003(K2,K3)
      IF(IPT.EQ.3) CALL XSE006(LIS1)
      IF(IPT.EQ.3) CALL XSE006(LIS2)
      IF(IPT.EQ.3) CALL XSE006(LOS1)
      IF(IPT.EQ.3) CALL XSE006(LOS2)
      IF(IPT.EQ.3) CALL XSE006(LOS3)
      RETURN
C
C
C
  250 CONTINUE
      LINE=LINE+6
      IF(LINE.LT.40) GO TO 265
      LINE=8
      PRINT 10
      PRINT 260,LABEL
  260 FORMAT(1H0,35X,13A6,/,1X,32HCALCULATED SYSTEM AND EQUIPMENT ,
     *       10HPARAMETERS)
  265 CONTINUE
      RTIMEH=RXNVOL/(SV(LOS3,41)/DL(SV(LOS3,5))*60.0*60.0)
      RTIMED=RTIMEH/24.0
      PRINT 30,LOCSV
      PRINT 270,RTIMEH,RTIMED
  270 FORMAT(/,6X,34HAPPROXIMATE POND RESIDENCE TIME = ,F6.1,3H HR,
     *       /,6X,34HAPPROXIMATE POND RESIDENCE TIME = ,F5.1,5H DAYS)
      RETURN
      END

@PRT,S    X.XE0006/
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```
390-1514*ASH(1).XEQ006(50)
      COMPILER (STD=66)
      SUBROUTINE XEQ006(P)
      COMMON/PAGE/LINE
C
C
C
      DOUBLE PRECISION LABEL,IDEQP
      COMMON/CMMN/SV(25,130),IDEQP(20),ISTM(25,10),ISEQ(25),PA(20,24),
     *            L(2),NL,LSRL(2),LERL(2),WV,DNAT(4),XA(4),LABEL(13),
     *            AH20
      COMMON/RATE/XMI(30),BB(30),RK(30),RM(30),VRK(30)
      COMMON/PPT/IRATE
      DIMENSION PP(4),P(24),IOPT(34),RATES(13)
      DATA RATES/0.0,.00128,11*0.0/
      LOCSL=ISEQ(NL)
C
C
C
C
C
C
C
      LIS=ISTM(LOCSL,1)
C
      LOS=ISTM(LOCSL,6)
C
C
C
      IF(SV(LOS,2).GT.1.5) RETURN
      IF(SV(LOS,2).GT.0.5) GO TO 11
C
      LINE=LINE+7
      IF(P(1).LE.1.5) LINE=LINE+9
      IF(LINE.LT.43) GO TO 3
      LINE=7
      IF(P(1).LE.1.5) LINE=16
C
      WRITE(6,2) LABEL
    2 FORMAT(1H1,1H+,34X,13A6,/,1X,31HSYSTEM AND EQUIPMENT PARAMETERS)
    3 WRITE(6,4) LOCSL
    4 FORMAT(/,5X,24HXEQ006, EQUIPMENT NUMBER,I3)
      OPTION=P(1)
      GAL=P(2)
      IF(OPTION.GT.1.5) GO TO 8
      VOL=GAL/7.480519
      VOLCM3=GAL*3785.43
      WSOL=SV(LIS,105)*100.
      WRITE(6,5) VOL,GAL
 5    FORMAT(10X,38HRATE CONSTANTS ARE USED IN CALCULATING,/,10X,
     139HTHE COMPOSITION OF THE LIQUID AND SOLID./,10X,
     217HPHASES IN RHTANK.,//,
     3 10X,9HVOLUME = ,1PE10.4,11H CU FT    = ,1PE10.4,5H GALS)
C
      DO 6 I=1,10
      VRK(I)=RATES(I)*VOLCM3*7.5
    6 IF(VRK(I).GT.0.0) IOPT(I+20)=1
      IF(OPTION.EQ.1.0) WRITE(6,7) (VRK(I),VRK(I+5),I=1,5)
 7    FORMAT(/,24X,13HRATE CONSTANT,19X,13HRATE CONSTANT,/,
     1 10X,9H SPECIES ,3X,17H(GMOLE/SEC CM SQ),3X,
     2 9H SPECIES ,3X,17H(GMOLE/SEC CM SQ),/,10X,
     3 2(9H*********,3X,17H*****************,3X),/,
     4 10X,4HSIO2,10X,1PE13.5,5X,9HCA3(PO4)2,5X,1PE13.5,/,
     5 10X,7HCA(OH)2,7X,1PE13.5,5X,6HCAHPO4,8X,1PE13.5,/,
     6 10X,5HCACO3,9X,1PE13.5,5X,7HMG(OH)2,7X,1PE13.5,/,
     7 10X,8HCASO4.2W,6X,1PE13.5,5X,8HMGCO3.5W,6X,1PE13.5,/,
     8 10X,8HCAH2SIO4,6X,1PE13.5,5X,9HSEPIOLITE,5X,1PE13.5)
C
      RETURN
C
 8    IF(OPTION.LT.2.5) WRITE(6,9)
 9    FORMAT(/,10X,34HLIQUID/SOLID EQUILIBRIA IS USED IN,/,10X,
     1 34HCALCULATING THE COMPOSITION OF THE,/,10X,
     2 33HLIQUID AND SOLID PHASES IN RHTANK)
      IF(OPTION.GE.2.5) WRITE(6,10)
 10   FORMAT(/,10X,39HTHE COMPOSITION IN RHTANK CONSISTS OF A,/,10X,
     1 36HSUPERSATURATED LIQUID WITH NO SOLID,/,10X,
     2 17HFORMATION ALLOWED)
C
      RETURN
C
   11 CONTINUE
C
C
      DO 12 I=1,19
 12   IOPT(I)=0.
```

```
      NS=0
      WNES=0.
      DO 13 I=5,130
   13 SV(LOS,I)=SV(LIS,I)
      IFLAG=1
      IOPT(19)=1
      IF(OPTION.LE.1.5) IRATE=1
      IF(OPTION.GT.2.5) NS=1
C
      CALL YEQU07(LOS,IOPT,SV(LOS,5),PP,WNES,NS)
C
      CALL XSEU05(0,0)
      RETURN
      END

@PRT,S    X.XEQ007/
```

```
390-1514*ASH(1).XEQ007(4)
              COMPILER (STD=66)
              SUBROUTINE XEQ007(P)
        C
        C
        C
        C
        C
        C
        C
        C
              DOUBLE PRECISION LABEL,IDEQP
              COMMON/CMMN/SV(25,130),IDEQP(20),ISTM(25,10),ISEQ(25),PA(20,24),
             *          L(2),NL,LSRL(2),LERL(2),WV,DNAT(4),XA(4),LABEL(13),
             *          AH2O
              COMMON/LCMN/XMW(100),DHF(100),ENTO(100),ACP(100),BCP(100),
             *          CCP(100),DCP(100),TMIN(100),TMAX(100),ZE(100),
             *          ALIT(100),BLIT(100),UCAP(100),SPGR(25)
              COMMON/PAGE/LINE
              COMMON/FLAG/IFLAG
              COMMON/RATE/XNI(30),BB(30),RK(30),RM(30),VRK(30)
              COMMON/RESEN/REN
              COMMON/DEBUG/IPT
              COMMON/PPT/IRATE
              COMMON/SSCHEM/XLIMSS(4),XSODSS(3),XMGSS(4),XCAUSS(3)
        C
              COMMON/APDRVR/APD(30)
              COMMON/CIRC/ALKDES,PHDES,QBD,KFLAG
              COMMON/FLAGS/KTRT,KWW,KAC,KFIX,IOUT,IUNITS,ISV
        C
              COMMON/SFTN/CAEFF,SLAPP
              DIMENSION P(1)
              DIMENSION XLIM(4),XSOD(3),XMG(4)
              DIMENSION PP(10),IOPT(34),TEST3(13),SOLIDS(13)
              DIMENSION ER(3),XX(3),RATES(13)
              DIMENSION DUMSOL(13)
              REAL LDS241,LDS341,NA2CO3,MGOH2
              INTEGER OPN,OLD
              DATA IOPT/34*0/,PP/10*0.0/,NEW/1/,OLD/2/,MID/3/
              DATA RATES/0.,.00128,11*0./
              DL(T)=0.99995282 + .467266E-4*(T-273.18) - .741051E-5*(T-273.18)**
             *      2 + .410796E-7*(T-273.18)**3 - .133707E-9*(T-273.18)**4
        C
```

```
C
C
C
C
C
C
C
C
C
      LOCSV=ISEQ(NL)
      LIS1=ISTM(LOCSV,1)
      LIS2=ISTM(LOCSV,2)
      LOS1=ISTM(LOCSV,6)
      LOS2=ISTM(LOCSV,7)
      LDS1=23
      LDS2=24
      LDS3=25
C
C
C
      XSOL=P(1)
      RXTIME=P(2)
      RECYCL=0.0
      RECYCL=P(3)
      KOPT=P(4)
      H2O=P(5)
      H2OCA=P(6)
      H2OMG=P(7)
      SFLIME=P(8)
      SFSODA=P(9)
      SFMG=P(10)
      CAEFF=P(11)
      SLAPP=P(12)
      PRECIP=P(13)
      SSGYP=P(14)
      IF(SV(LIS1,2).GT.1.5) RETURN
      CHECK=0
      ICOUNT=0
      KCOUNT=0
      ICNVG=0
      IF(SV(LIS1,2).GT.1.5) GO TO 425
      IF(SV(LIS1,2).GT.0.5) GO TO 75
C
```

```
C
C
      LINE=LINE + 12
      IF(LINE.LT.43) GO TO 25
      LINE=14
      PRINT 10
   10 FORMAT (1H1)
      PRINT 20, LABEL
   20 FORMAT (1H0,35X,13A6,/,1X,31HSYSTEM AND EQUIPMENT PARAMETERS)
   25 CONTINUE
      PRINT 30, LOCSV
   30 FORMAT(/,1H0,4X,24HXEQ007, EQUIPMENT NUMBER,I3)
      PRINT 40, XSOL, RXTIME, RECYCL
   40 FORMAT(/,6X,31HWT. PERCENT SOLIDS IN SLUDGE = ,F4.1,/,1H ,5X,
     *         25HREACTOR RESIDENCE TIME = ,F5.1,5H MIN.,/,1H ,5X,
     *         22HSLUDGE RECYCLE RATE = ,F5.1,8H GAL/MIN)
      PRINT 45,SFLIME,SFSODA,SFMG
   45 FORMAT (6X,46HUSER INPUT STOICHIOMETRIC FACTORS FOR CHEMICAL
     *          9H ADDITION,/,9X,10HCA(OH)2 = ,F6.3,/,9X,10HNA2CO3  = ,
     *          F6.3,/,9X,10HMG(OH)2 = ,F6.3)
      IF(KOPT.GT.0) GO TO 55
      PRINT 50, H20
   50 FORMAT(6X,40HRETURN H20 IS ADJUSTED TO A PH VALUE OF ,F3.1)
      GO TO 65
   55 CONTINUE
      PRINT 60, H20
   60 FORMAT(6X,46HRETURN H20 IS ADJUSTED TO AN ALKALINITY VALUE,
     *         3H OF,F5.1,13H PPM AS CACO3)
   65 CONTINUE
      PRINT 70, H20CA, H20MG
   70 FORMAT(6X,44HSOLIDS (CACO3) CARRY-OVER IN RETURN H20   = ,
     *         F5.1,4H PPM,/,1H ,5X,31HSOLIDS (MG(OH)2) CARRY-OVER IN ,
     *         13HRETURN H20 = ,F5.1,4H PPM)
      IF(CAEFF.GT.0.0) PRINT 71,CAEFF
   71 FORMAT(6X,"USER SPECIFIED EFFLUENT CA CONC.",F5.1,"  MG/L")
      IF(SLAPP.GT.0.0) PRINT 72,SLAPP
   72 FORMAT(6X,"USER SPECIFIED APPROACH TO S/L EQ.",F5.1)
      RETURN
   75 CONTINUE
      IF(KFIX.EQ.2) GO TO 3333
C
C
      IF(IPT.EQ.2) CALL XSE006(12)
      ICA=0
      ISSKNT=0
      ISSCNT=ISSCNT+1
      IF(SV(13,41).LE.0.0) SV(13,41)=0.25*SV(12,41)
      SV(12,40)=SV(11,40)
      RCAOLD=SV(12,20)
      CALL XSE008(12,1)
      NS=1
      IOPT(1)=1
      IOPT(19)=1
      IF(SSGYP.LE.0.0) SSGYP=1.0
      ITRCNT=0
 2000 CONTINUE
      ITRCNT=ITRCNT+1
      IF(ITRCNT.GT.20) GO TO 3500
      CALL YEQ001(12,IOPT,SV(12,5),PP,WNES,NS)
      PRINT 2001,ITRCNT,SV(13,41),SSGYP,SV(12,100),SV(12,20)
 2001 FORMAT(10X,'ITR  FLOW  SSGYP  GYPCALC 1220',I3,4E10.4)
      IF(SV(12,100).LE.SSGYP.AND.ISSCNT.LE.1) GO TO 2002
      GO TO 2004
 2002 PRINT 2003,SV(12,100),SSGYP
 2003 FORMAT(10X,'SIDESTREAM SOFTENER  HAS BEEN SPECIFIED, BUT
     C   THE',/,' RECIRC. WATER RSGYP VALUE',E10.4,'  IS LESS
     C   THAN',/,'THE DESIRED VALUE',E10.4)
      STOP
 2004 CONTINUE
      RSER=SV(12,100)-SSGYP
      IF(ABS(RSER)/SSGYP.LE.0.05) GO TO 3332
      IF(RSER.LT.0.0) GO TO 2005
C
      CAHIGH=SV(12,20)
      IF(ICA.EQ.2) GO TO 3000
      ICA=1
      SV(12,20)=0.5*CAHIGH
      GO TO 2006
 2005 CONTINUE
C
      CALOW=SV(12,20)
      IF(ICA.EQ.1) GO TO 3000
      ICA=2
      SV(12,20)=2.0*CAHIGH
 2006 CONTINUE
      GO TO 2000
 3000 CONTINUE
      IITR=IITR+1
      IF(IITR.GT.20) GO TO 3500
      PRINT 3001,IITR,SV(12,20),CALOW,CAINT,CAHIGH
 3001 FORMAT(10X,'VALUE BRACKETED  ITR#  CAACT  L I H',I3,4E10.4)
C
      SV(12,20)=0.5*(CAHIGH+CALOW)
      CALL YEQ001(12,IOPT,SV(12,5),PP,WNES,NS)
      RSERR=SV(12,100)-SSGYP
      IF(ABS(RSERR)/SSGYP.LE.0.05) GO TO 3332
      CAINT=SV(12,20)
      IF(RSERR.GT.0.0) GO TO 2007
      CALOW=CAINT
      GO TO 3000
 2007 CONTINUE
      CAHIGH=CAINT
      GO TO 3000
 3332 CONTINUE
      CAREMR=RCAOLD-SV(12,20)
      SV(12,20)=RCAOLD
      CALL YEQ001(12,IOPT,SV(12,5),PP,WNES,NS)
      PRINT 9999
 9999 FORMAT(10X,'AFTER 3332')
      IF(IPT.EQ.2) CALL XSE006(12)
      CALL XSE008(9,1)
      IF(SV(9,20).LE.0.0) PPMCAO=14.0
      IF(SV(9,20).GT.0.0) PPMCAO=SV(9,20)*40.08*1000000./SV(9,41)
      PPMCAI=SV(12,20)*40.08*1000000./SV(12,41)
      SV(13,41)=CAREMR*40.08*1000000./(PPMCAI-PPMCAO)
      PRINT 9876,PPMCAI,PPMCAO,SV(13,41)
 9876 FORMAT(10X,'PPMCAI   PPMCAO   SV(13,41)',3E10.4)
      GO TO 3333
 3500 PRINT 3501
 3501 FORMAT(10X,'XEQ007 COULD NOT CONVRG ON TREAT RATE')
      STOP
 3333 CONTINUE
C
C
C
C
C
      KCOUNT=KCOUNT+1
      OPN=1
      CALL XSE008 (LIS2,OPN)
      DO 82 I=1,4
      XLIM(I)=XLIMSS(I)
      IF(I.GT.3) GO TO 82
      XSOD(I)=XSODSS(I)
   82 CONTINUE
      CRBALK=(SV(LIS2,52)+SV(LIS2,57)+SV(LIS2,61)+SV(LIS2,67)
     1        +SV(LIS2,84))*SV(LIS2,41)/1000.0
      BCBALK=(SV(LIS2,45)+SV(LIS2,51)+SV(LIS2,56)+SV(LIS2,60)
     1        +SV(LIS2,68))*SV(LIS2,41)/1000.0
      IF (XLIM(4).GT.0.0) GO TO 88
      IF (SFLIME.LE.0.0) GO TO 88
      IF(SV(LIS2,20)-BCBALK) 84,85,85
   84 SV(LIS1,106)=SV(LIS2,20)/2.0+10.0/100.0*SV(LIS2,21)
      GO TO 86
   85 SV(LIS1,106)=BCBALK/2.0+10.0/100.0*SV(LIS2,21)
   86 SV(LIS1,106)=SV(LIS1,106)*SFLIME
      IF(SV(LIS2,41).LE.0.0) GO TO 550
      CAOH2=SV(LIS1,106)
      SV(LIS1,111)=SV(LIS1,106)*XMW(26)/XLIM(1)*XLIM(2)/XMW(31)
      SV(LIS1,118)=SV(LIS1,106)*XMW(26)/XLIM(1)*XLIM(3)/XMW(38)
   88 CONTINUE
      IF(SV(LIS2,20)-BCBALK) 89,90,90
   89 IF(SFLIME.LE.0.0) SFLIM1=SV(LIS1,106)/
     1      (SV(LIS2,20)/2.0+10.0/100.0*SV(LIS2,21))
      GO TO 93
   90 IF(SFLIME.LE.0.0) SFLIM1=SV(LIS1,106)/
     1      (BCBALK/2.0+(10.0/100.0)*SV(LIS2,21))
   93 CONTINUE
      IF (XSOD(3).GT.0.0) GO TO 96
      IF (SFSODA.LE.0.0) GO TO 96
      SV(LIS1,117)=SV(LIS2,20)+SV(LIS1,106)-(BCBALK+CRBALK+SV(LIS2,44)
     1          *SV(LIS2,41)/1000.0)
      IF(SV(LIS1,117).GT.0.0) GO TO 92
      SV(LIS1,117)=0.0
      CAVAL=SV(LIS2,20)+SV(LIS1,106)
      PRINT 91,CAVAL,BCBALK,SFSODA
   91 FORMAT (1H0,14X,27H*****WARNING IN XEQ007*****,/,1H0,5X,
     1         47HPRELIMINARY CALCULATIONS INDICATE THAT SODA ASH,
     2         23HADDITION IS UNNECESSARY,/,5X,12HLIQUID CA = ,F8.6,
     3         36HG-MOLE/MIN     AND BICARBONATE ALK = ,F8.6,/,5X,
     4         10HG-MOLE/MIN,/,5X,
     5         43HTHE USER HAS SPECIFIED A STOICH. FACTOR OF ,F6.3)
   92 CONTINUE
      SV(LIS1,117)=SV(LIS1,117)*SFSODA
      NA2CO3=SV(LIS1,117)
      SV(LIS1,118)=SV(LIS1,118)+SV(LIS1,117)*XMW(37)/XSOD(1)*XSOD(2)/
     *                XMW(38)
   96 CONTINUE
      IF(SV(LIS1,117).LE.0.0) GO TO 97
      IF(SFSODA.LE.0.0) SFSOD1=SV(LIS1,117)/
     1  (SV(LIS2,20)+SV(LIS1,106)-(BCBALK+CRBALK-35.0/100000000.
     2  *SV(LIS2,41)))
   97 CONTINUE
      IF (XMGSS(4).GT.0.0) GO TO 104
      IF (SFMG.LE.0.0) GO TO 104
      TESTMG=SV(LIS2,29)-SV(LIS1,111)/(5.0-0.05*(SV(LIS2,5)-283.0))
      IF (TESTMG) 98,98,102
   98 PRINT 100,SFMG
  100 FORMAT (1H0,14X,29H***** WARNING IN  *****,/,1H0,5X,
     *          46HPRELIMINARY CALCULATIONS INDICATE THAT MG(OH)2
     *          24H ADDITION IS UNNECESSARY,/,5X,22HTHE USER HAS SPECIFIED
     *          28H A STOICHIOMETRIC FACTOR OF ,F6.3,12H FOR MG(OH)2
     *          9H ADDITION,/,5X,25HTHIS AMOUNT WILL BE ADDED)
      TESTMG=-1.0*TESTMG
  102 SV1111=SV(LIS1,111)
      SV(LIS1,111)=SFMG*(5.0-0.05*(SV(LIS2,5)-283.0))*TESTMG+
     *   SV(LIS1,111)
      MGOH2=SV(LIS1,111)
      SV(LIS1,106)=SV(LIS1,111)*XMW(31)/XMGSS(1)*XMGSS(2)/XMW(26)+
     *                SV(LIS1,106)
      SV(LIS1,118)=SV(LIS1,111)*XMW(31)/XMGSS(1)*XMGSS(3)/XMW(38)+
     *                SV(LIS1,118)
  104 CONTINUE
      IF(TESTMG.LE.0.0) GO TO 105
      IF(SFMG.LE.0.0) SFMG=(SV(LIS1,111)-SV1111)/
     *     ((5.-.05*(SV(LIS2,5)-283.))*TESTMG)
  105 CONTINUE
C
C
C
C
      OPN=2
      CALL XSE008 (LIS1,OPN)
      OPN=3
      CALL XSE008 (LIS2,OPN)
      DO 107 I=1,13
      SV(LDS1,I+19)=SV(LIS1,I+19)+SV(LIS2,I+19)
  107 CONTINUE
  800 CONTINUE
      SV(LDS1,5)=SV(LIS2,5)
      SV(LDS1,6)=SV(LIS2,6)
      IOPT(1)=0
      IOPT(19)=1
      NS=0
      IFLAG=1
      CALL YEQU01(LDS1,IOPT,SV(LDS1,5),PP,WNES,NS)
      IFLAG=1
C
C
C
C
      IF(CAEFF.EQ.0.0.AND.SLAPP.EQ.0.0) GO TO 3005
      AQCA=(SV(LDS1,50)+SV(LDS1,51)+SV(LDS1,52)+SV(LDS1,53)+
     *       SV(LDS1,54)+SV(LDS1,72)+SV(LDS1,73)+SV(LDS1,74)+
     *       SV(LDS1,78))*40.0*1000.0
      IF(CAEFF.GT.0.0.AND.AQCA.GE.CAEFF) GO TO 3005
      SOLCA=(SV(LDS1,106)+SV(LDS1,107)+3.*SV(LDS1,108)+
     *        SV(LDS1,109)+SV(LDS1,110)+SV(LDS1,114)
     *       +SV(LDS1,116))*40.0*1000.0*1000.0/SV(LDS1,41)
      APPEQ=(SOLCA-(CAEFF-AQCA))/SOLCA
      IF(SLAPP.NE.0.0) APPEQ=SLAPP
      IF(APPEQ.LE.0.0) APPEQ=0.0
      DO 3006 K=1,13
      IF(SV(LDS1,105+K).LE.0.0) GO TO 3006
      DUMSOL(K)=APPEQ*SV(LDS1,105+K)
      SV(LDS1,105+K)=SV(LDS1,105+K)-DUMSOL(K)
 3006 CONTINUE
      OPN=3
      CALL XSE008(LDS1,OPN)
      NS=1
      CALL YEQU01(LDS1,IOPT,SV(LDS1,5),PP,WNES,NS)
      NS=0
      DO 3007 K=1,13
      IF(DUMSOL(K).LE.0.0) GO TO 3007
      SV(LDS1,105+K)=DUMSOL(K)
      DUMSOL(K)=0.0
 3007 CONTINUE
      CALL XSE008(LDS1,OPN)
      IF(IPT.EQ.2) PRINT 4003
 4003 FORMAT(10X,'AFTER 3007')
      IF(IPT.EQ.2) CALL XSE006(LDS1)
C
C
C
      WSLSOL=XSEU09(LDS1,4)
      WSLLIQ=WSLSOL/(XSOL/100.0)-WSLSOL
      SV(LOS1,41)=WSLLIQ
      SV(LOS2,41)=SV(LDS1,41)-SV(LOS1,41)
      SV(LDS2,41)=SV(LOS2,41)
C
C
C
      DO 394 II=1,13
      SV(LOS1,II+105)=SV(LDS1,II+105)
      SV(LDS1,II+105)=0.0
      SV(LDS2,II+105)=0.0
C
      IF(II.EQ.2) SV(LDS2,II+105)=H2OCA/1000000.*SV(LOS2,41)/100.
      IF(II.EQ.6) SV(LDS2,II+105)=H2OMG/1000000.*SV(LOS2,41)/58.3
      SV(LOS1,II+105)=SV(LOS1,II+105)-SV(LDS2,II+105)
  394 CONTINUE
C
C
C
      SV(LOS1,5)=SV(LIS2,5)
      SV(LOS1,6)=SV(LIS2,6)
      SV(LDS2,5)=SV(LIS2,5)
      SV(LDS2,6)=SV(LIS2,6)
      DO 395 II=1,47
      SV(LOS1,II+41)=SV(LDS1,II+41)
      SV(LOS2,II+41)=SV(LDS1,II+41)
      SV(LDS2,II+41)=SV(LDS1,II+41)
  395 CONTINUE
      IF(IPT.EQ.2) PRINT 4000
 4000 FORMAT(10X,'AFTER 395 CONTINUE')
      CALL XSEU08(LOS1,3)
      CALL XSEU08(LDS2,1)
      IF(IPT.EQ.2) CALL XSE006(LOS1)
      IF(IPT.EQ.2) CALL XSE006(LDS2)
      GO TO 252
 3005 CONTINUE
```

```
C
C
C
      IF(SV(LDS1,107).GT.0.) GO TO 108
      PRINT 111
  111 FORMAT(1H0,10X,29H*****  ERROR IN    *****,/,1H0,5X,
     *   35HLIME ADDITION RATE INSUFFICIENT TO ,/,5X,
     *   32HPRECIPITATE CACO3. TRY A HIGHER ,/,5X,14HSTOICHIOMETRY.)
      STOP
  108 CONTINUE
      SV(LDS1,118)=SV(LIS1,118)+SV(LIS2,118)+SV(LDS3,118)
C
C
C
      IF(PRECIP.EQ.0.0) GO TO 117
  110 CONTINUE
C
C
C
      RHOH20=DL(SV(LIS2,5))
      K=3
      WLIQ=XSE009(LIS2,K)
      RXNVOL=WLIQ/RHOH20
      DO 106 I=1,13
      RXNVOL=RXNVOL+SV(LIS1,I+105)*XMW(I+25)/(SPGR(I)*RHOH20)
     *       +SV(LIS2,I+105)*XMW(I+25)/(SPGR(I)*RHOH20)
  106 CONTINUE
      RXNVOL=RXNVOL+RECYCL*63.0835
      RXNVOL=RXNVOL*RXTIME*60.0
      DO 109 I=1,12
      VRK(I)=RATES(I)*RXNVOL*7.5
  109 CONTINUE
      IF(ICOUNT.LE.40) GO TO 215
      PRINT 112, ICOUNT
  112 FORMAT(1H0,15X,33H***** FATAL ERROR IN  *****,/,1H0,5X,
     *       42HFAILURE TO CONVERGE ON REACTOR CONTENTS IN,I3,
     *       11H ITERATIONS)
      CALL XSE006(LDS1)
      CALL XSE006(LDS2)
      CALL XSE006(LDS3)
      STOP
  117 CONTINUE
C
```

```
C
C
C
C
      K=5
      WSOL=XSEUD9(LDS1,K)
      K=1
      WTOT=XSEUD9(LDS1,K)
      IF(WTOT.GT.0.0) SV(LDS1,105)=WSOL/WTOT
      DIFF=(XSOL/100.0)-SV(LDS1,105)
      IF(DIFF.GT.0.0) GO TO 130
      XSOL1=SV(LDS1,105)*100.0
      PRINT 120, XSOL1, XSOL
  120 FORMAT(1H0,15X,33H***** FATAL ERROR IN  *****,/,1H0,5X,
     *        52HWEIGHT PERCENT SOLIDS IN SLUDGE IS CALCULATED TO BE ,
     *        F5.1,/,1H ,5X,23HTHIS VALUE EXCEEDS THE ,F5.1,
     *        35H WT. % SOLIDS SPECIFIED BY THE USER)
      CALL XSEUD6(LDS1)
      STOP
  130 CONTINUE
      K=3
      WLIQ=XSEUD9(LDS1,K)
C
C
C
C
      BDWTOT=WSOL/(XSOL/100.0)
      BDWLIQ=BDWTOT-WSOL
      SV(LDS3,41)=(BDWLIQ/WLIQ)*SV(LDS1,41)
      RECYCL=P(3)/100.*SV(LDS3,41)*.01585
  131 CONTINUE
      IF(ICOUNT.EQ.0) LDS341=SV(LDS3,41)
      DO 132 I=1,47
      SV(LDS3,I+41)=SV(LDS1,I+41)
  132 CONTINUE
      DO 134 I=1,13
      SV(LDS3,I+105)=SV(LDS1,I+105)
  134 CONTINUE
C
C
C
      RCL=SV(LDS3,41)/DL(SV(LDS1,5))
      DO 135 I=1,47
      RCL=RCL+SV(LDS3,I+41)*XMW(I+45)*SV(LDS3,41)/(1000.0*
     *    DL(SV(LDS1,5)))
  135 CONTINUE
      RCS=0.0
      DO 136 I=1,13
      RCS=RCS+SV(LDS3,I+105)*XMW(I+25)/(SPGR(I)*DL(SV(LDS1,5)))
  136 CONTINUE
      RCT=(RCL+RCS)*0.01585
      FACTOR=RECYCL/RCT
      SV(LDS3,41)=FACTOR*SV(LDS3,41)
      DO 138 I=1,13
      SV(LDS3,I+105)=FACTOR*SV(LDS3,I+105)
  138 CONTINUE
      OPN=3
      CALL XSE008(LDS3,OPN)
  139 CONTINUE
      SV(LDS2,41)=SV(LDS1,41)-SV(LDS3,41)
      RWSOL=(H2OCA+H2OMG)*0.0008327*SV(LDS2,41)/(1000.0*DL(SV(LDS1,5)))
  140 CONTINUE
      ICNT=0
      IF(WSOL.GT.RWSOL) GO TO 146
      PRINT 143,WSOL,RWSOL
  143 FORMAT(1H0,15X,33H***** FATAL ERROR IN  *****,/,1H0,5X,
     *        33HTOTAL SOLIDS FLOW IN CLARIFIER = ,F8.2,10H GRAMS/SEC,
     *        /,1H ,5X,45HTHIS VALUE IS LESS THAN THE SOLIDS CARRY-OVER,
     *        23H SPECIFIED BY THE USER ,F8.2,10H GRAMS/SEC)
      CALL XSE006(LDS1)
      CALL XSE006(LDS2)
      CALL XSE006(LDS3)
      STOP
  146 CONTINUE
C
C
C
      BDWSOL=WSOL-RWSOL
      BDWTOT=BDWSOL/(XSOL/100.0)
      BDWLIQ=BDWTOT-BDWSOL
      SV(LDS3,41)=(BDWLIQ/WLIQ)*SV(LDS1,41)
      SV(LDS2,41)=SV(LDS1,41)-SV(LDS3,41)
      RWSOL1=(H2OCA+H2OMG)*0.0008327*SV(LDS2,41)/(1000.0*DL(SV(LDS1,5)))
      IF(RWSOL.LE.0.) GO TO 150
      TEST=(RWSOL-RWSOL1)/RWSOL*100.0
      TEST=ABS(TEST)
      IF(TEST.LE.0.001) GO TO 150
      RWSOL=RWSOL1
      ICNT=ICNT+1
      IF(ICNT.LT.25) GO TO 140
  150 CONTINUE
C
C
C
C
      VOLBDL=SV(LDS3,41)/DL(SV(LDS1,5))
      DO 155 I=1,47
      VOLBDL=VOLBDL+SV(LDS3,I+41)*XMW(I+45)*SV(LDS3,41)/(1000.0*
     *        DL(SV(LDS1,5)))
  155 CONTINUE
      VOLBDS=0.0
      DO 160 I=1,13
      VOLBDS=VOLBDS+(BDWSOL/WSOL)*SV(LDS1,I+105)*XMW(I+25)/(SPGR(I)*
     *        DL(SV(LIS2,5)))
  160 CONTINUE
      BDVOL=(VOLBDL+VOLBDS)*0.01585
      IF (BDVOL.GE.RECYCL) GO TO 180
      PRINT 170, BDVOL, RECYCL
  170 FORMAT(1H0,15X,27H***** ERROR IN  *****,/,1H0,5X,
     *        49HTOTAL SLUDGE BLOWDOWN VOLUME IS CALCULATED TO BE ,F5.1,
     *        8H GAL/MIN,/,1H ,5X,28HTHIS VALUE IS LESS THAN THE ,F5.1,
     *        34H GPM SLUDGE RECYCLE RATE SPECIFIED,/,1H ,5X,
     *        12H BY THE USER)
      CALL XSE006(LDS3)
      STOP
  180 CONTINUE
C
C
C
C
      TEST1=(LDS341-SV(LDS3,41))*100.0/LDS341
      TEST1=ABS(TEST1)
      TEST2=(SV(LDS3,52)-SV(LDS1,52))*100.0/SV(LDS3,52)
      TEST2=ABS(TEST2)
      DO 183 I=1,13
      TEST3(I)=0.
      IF(SOLIDS(I).LE.0.) GO TO 183
      TEST3(I)=(SOLIDS(I)-SV(LDS1,I+105))*100.0/SOLIDS(I)
      TEST3(I)=ABS(TEST3(I))
  183 CONTINUE
      PROD=0.0
      IF(TEST1.GT..1) GO TO 190
      PROD=1.0
      DO 189 I=1,13
      IF(I.NE.2) TEST3(I)=0.
      IF(TEST3(I).LE..10) GO TO 185
      CHECK=0.0
      GO TO 187
  185 CONTINUE
      CHECK=1.0
  187 CONTINUE
      PROD=PROD*CHECK
  189 CONTINUE
  190 CONTINUE
      ICOUNT=ICOUNT+1
      SV(LDS2,41)=(1.0-(RECYCL/BDVOL))*SV(LDS3,41)
      LDS341=SV(LDS3,41)
      LDS241=SV(LDS2,41)
      SV(LDS3,41)=SV(LDS3,41)-SV(LDS2,41)
      DO 200 I=1,47
      SV(LDS2,I+41)=SV(LDS1,I+41)
      SV(LDS3,I+41)=SV(LDS1,I+41)
      SV(LDS2,I+41)=SV(LDS1,I+41)
  200 CONTINUE
      DO 210 I=1,13
      IF(SV(LDS1,I+105).LE.0.0) GO TO 210
      SV(LDS2,I+105)=0.0
      IF(I.EQ.2) SV(LDS2,I+105)=H2OCA/1000000.0*SV(LDS2,41)/100.0
      IF(I.EQ.6) SV(LDS2,I+105)=H2OMG/1000000.0*SV(LDS2,41)/58.3
      SV(LDS3,I+105)=SV(LDS1,I+105)-SV(LDS2,I+105)
      SV(LDS2,I+105)=SV(LDS3,I+105)*(1.0-(RECYCL/BDVOL))
      SV(LDS3,I+105)=SV(LDS3,I+105)-SV(LDS2,I+105)
  210 CONTINUE
      OPN=3
      CALL XSE008 (LDS2,OPN)
      CALL XSE008 (LDS3,OPN)
      IF(PROD.GT.0.0) GO TO 230
      GO TO 110
  215 CONTINUE
C
C
C
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      OPN=2
      CALL XSE008 (LIS1,OPN)
      DO 220 I=1,13
      SV(LDS1,I+19)=SV(LIS1,I+19)+SV(LIS2,I+19)+SV(LDS3,I+19)
      XNI(I)=SV(LIS1,I+105)+SV(LIS2,I+105)+SV(LDS3,I+105)
      SOLIDS(I)=SV(LDS1,I+105)
  220 CONTINUE
C
C
C
      IF(PRECIP.EQ.0.0) GO TO 800
  230 CONTINUE
      IRATE=0
      IOPT(22)=0
      OPN=3
      CALL XSE008(LOS2,OPN)
      DO 240 I=1,6
      SV(LDS2,I)=SV(LDS1,I)
      SV(LDS3,I)=SV(LDS1,I)
      SV(LOS2,I)=SV(LDS1,I)
  240 CONTINUE
      SV(LDS2,40)=SV(LDS1,40)
      SV(LOS2,40)=SV(LDS1,40)
      SV(LOS2,105)=BDWSOL/BDWTOT
      SO4I=SV(LDS2,28)
      OPN=1
      CALL XSE008 (LIS1,OPN)
      DO 250 I=1,12
      SV(LDS2,I+19)=SV(LDS2,I+19)+SV(LIS1,I+19)
  250 CONTINUE
      DO 252 I=1,11
      APD(I)=1.0
  252 CONTINUE
      IF(KFIX.EQ.2) GO TO 3334
      IF(KFIX.EQ.1.AND.ISSKNT.GE.1) GO TO 3334
      ISSKNT=ISSKNT+1
      CAREMA=(RCAOLD*SV(13,41)/SV(12,41))-SV(LDS2,20)
      PRINT 3351,ISSKNT,CAREMA,RCAOLD,SV(LDS2,20),SV(13,41)
 3351 FORMAT(10X,'ADJ SSTRT, CA REM,CAIN,CAOUT,SSTRTR',I3,4E10.3)
      IF(ABS(CAREMA-CAREMR)/CAREMR.LE.0.05) GO TO 3334
      SV(13,41)=(CAREMR/CAREMA)*SV(13,41)
      PRINT 3352,SV(13,41)
 3352 FORMAT(10X,'NEW TRT RATE',E10.4)
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      IF(SV(13,41).LE.SV(12,41)) GO TO 3333
      PRINT 3355
 3355 FORMAT(10X,'REQ. SSTREAT RATE IS GREATER THEN RECIRC')
      STOP
 3334 CONTINUE
C
C
C
      NCOUNT=0
      DO 260 I=1,3
      ER(I)=0.0
      XX(I)=0.0
  260 CONTINUE
      IOPT(1)=1
      IOPT(19)=1
      IOPT(26)=0
      IFLAG=1
      IF(KOPT.GT.0) GO TO 320
C
C
C
      SV(LDS2,40)=H2O
  270 CONTINUE
      CALL YEQU01(LDS2,IOPT,SV(LDS2,5),PP,WNES,NS)
      NCOUNT=NCOUNT+1
      IF(ABS(REN).LE.1.E-6) GO TO 400
      IF(NCOUNT.GT.1) GO TO 280
      XX(OLD)=SV(LDS2,28)
      XX(NEW)=1.1*XX(OLD)
      ER(OLD)=REN
      GO TO 290
  280 CONTINUE
      ER(NEW)=REN
      DER=(ER(NEW)-ER(OLD))/(XX(NEW)-XX(OLD))
      XX(OLD)=XX(NEW)
      ER(OLD)=ER(NEW)
      XX(NEW)=XX(NEW)-ER(NEW)/DER
  290 CONTINUE
      SV(LDS2,28)=XX(NEW)
      IF(NCOUNT.GT.15) GO TO 300
      GO TO 270
  300 CONTINUE
      PRINT 310,SV(LDS2,40),NCOUNT
  310 FORMAT(1H0,15X,33H***** FATAL ERROR IN XEQ007 *****,/,1H0,5X,
     *          29HFAILURE TO CONVERGE ON PH OF ,F4.1,
     *          17H FOR RETURN WATER,/,1H ,5X,23HNUMBER OF ITERATIONS = ,
     *          I2)
      CALL XSE006(LDS2)
      STOP
C
C
C
  320 CONTINUE
      XX(NEW)=SV(LDS2,28)
      IOPT(1)=0
  325 CONTINUE
      CALL YEQ001(LDS2,IOPT,SV(LDS2,5),PP,WNES,NS)
      NCOUNT=NCOUNT+1
      ALKEQ=2.0*(SV(LDS2,52)+SV(LDS2,57)+SV(LDS2,61)+SV(LDS2,67))+
     *             SV(LDS2,45)+SV(LDS2,51)+SV(LDS2,56)+SV(LDS2,60)+
     *             SV(LDS2,68)+SV(LDS2,42)-(SV(LDS2,43)+SV(LDS2,50)+
     *             SV(LDS2,55)+SV(LDS2,59))
      ALKEQ=ALKEQ*0.05004
      ATEST=(H20-ALKEQ)/H20*100.0
      IF(ABS(ATEST).LE.0.05) GO TO 400
      ACHECK=ER(OLD)*ATEST
      IF(ACHECK.LT.0.0) GO TO 350
      IF(ATEST.LT.0.0) GO TO 330
      XX(OLD)=XX(NEW)
      XX(NEW)=0.9*XX(OLD)
      GO TO 340
  330 CONTINUE
      XX(OLD)=XX(NEW)
      XX(NEW)=1.1*XX(OLD)
  340 CONTINUE
      ER(OLD)=ATEST
      IF(NCOUNT.GT.15) GO TO 380
      SV(LDS2,28)=XX(NEW)
      GO TO 325
  350 CONTINUE
      ER(NEW)=ATEST
  360 CONTINUE
      XX(MID)=(XX(NEW)+XX(OLD))/2.0
      IF(NCOUNT.GT.15) GO TO 380
      SV(LDS2,28)=XX(MID)
      CALL YEQ001(LDS2,IOPT,SV(LDS2,5),PP,WNES,NS)
      NCOUNT=NCOUNT+1
      ALKEQ=2.0*(SV(LDS2,52)+SV(LDS2,57)+SV(LDS2,61)+SV(LDS2,67))+
     *          SV(LDS2,45)+SV(LDS2,51)+SV(LDS2,56)+SV(LDS2,60)+
     *          SV(LDS2,68)+SV(LDS2,42)-(SV(LDS2,43)+SV(LDS2,50)+
     *          SV(LDS2,55)+SV(LDS2,59))
      ALKEQ=ALKEQ*0.05004
      ATEST=(H2O-ALKEQ)/H2O*100.0
      IF(ABS(ATEST).LE.0.05) GO TO 400
      ACHECK=ER(NEW)*ATEST
      IF(ACHECK.LT.0.0) GO TO 370
      ER(NEW)=ATEST
      XX(NEW)=XX(MID)
      GO TO 360
  370 CONTINUE
      ER(OLD)=ATEST
      XX(OLD)=XX(MID)
      GO TO 360
  380 CONTINUE
      PRINT 390,ALKEQ,H2O,NCOUNT
  390 FORMAT(1H0,15X,27H***** ERROR IN XEQ007 *****,/,1H0,5X,
     *       49HFAILURE TO CONVERGE ON ALKALINITY OF RETURN WATER,/,1H ,
     *       7X,24HCALCULATED ALKALINITY = ,F5.1,13H PPM AS CACO3,/,1H ,
     *       7X,21HDESIRED ALKALINITY = ,F5.1,13H PPM AS CACO3,/,1H ,
     *       7X,23HNUMBER OF ITERATIONS = ,I2)
      CALL XSE006(LDS2)
      STOP
C
C
C
  400 CONTINUE
      IOPT(1)=0
      ACID=SV(LDS2,28)-SO4I
      SV(LIS1,41)=ACID*(0.02)/(0.98/98.07754)
      SV(LIS1,42)=2.0*ACID*1000.0/SV(LIS1,41)
      SV(LIS1,86)=ACID*1000.0/SV(LIS1,41)
      ACID=ACID*98.07754*7.93664
      OPN=3
      CALL XSE008 (LIS1,OPN)
      CALL XSE008 (LDS2,OPN)
      DO 410 I=1,130
      SV(LOS2,I)=SV(LDS2,I)
  410 CONTINUE
      K1=0
      K2=0
      CALL XSE003 (K1,K2)
      IF(IPT.EQ.1) CALL XSE006(LIS1)
      IF(IPT.EQ.1) CALL XSE006(LIS2)
      IF(IPT.EQ.1) CALL XSE006(LOS1)
      IF(IPT.EQ.1) CALL XSE006(LOS2)
      IF(IPT.EQ.1) CALL XSE006(23)
      IF(IPT.EQ.1) CALL XSE006(24)
      IF(IPT.EQ.1) CALL XSE006(25)
      RHOH2O=DL(SV(LIS2,5))
      K=3
      WLIQ=XSE009(LIS2,K)
      RXNVOL=WLIQ/RHOH2O
      DO 420 I=1,13
      RXNVOL=RXNVOL+SV(LIS1,I+105)*XMW(I+25)/(SPGR(I)*RHOH2O)+
     *       SV(LIS2,I+105)*XMW(I+25)/(SPGR(I)*RHOH2O)
  420 CONTINUE
      RCYCLE=SV(LDS3,41)*0.015852/RHOH2O
      IF(LOCSV.EQ.12) RCYCLS=RCYCLE
      IF(LOCSV.NE.12) RCYCLM=RCYCLE
      RXNVOL=RXNVOL+RCYCLE*63.0835
      RXNVOL=RXNVOL*RXTIME*60.0
      RVM3=RXNVOL*1.E-6
      RVFT3=RXNVOL*3.5314E-5
      IF(LOCSV.EQ.12) RVGAL=RXNVOL*2.64173E-4
      IF(LOCSV.NE.12) RVGAL1=RXNVOL*2.64173E-4
      IF(IPT.EQ.2) CALL XSE006(LIS1)
      IF(IPT.EQ.2) CALL XSE006(LIS2)
      IF(IPT.EQ.2) CALL XSE006(LOS1)
      IF(IPT.EQ.2) CALL XSE006(LOS2)
      IF(IPT.EQ.2) CALL XSE006(23)
      IF(IPT.EQ.2) CALL XSE006(24)
      IF(IPT.EQ.2) CALL XSE006(25)
      GO TO 488
  425 CONTINUE
C
C
C
      LINE=LINE+13
      IF(LINE.LT.43) GO TO 435
      LINE=15
      PRINT 430
  430 FORMAT(1H1)
  435 CONTINUE
      PRINT 440,LABEL
  440 FORMAT (1H0,35X,13A6,/,1X,31HSYSTEM AND EQUIPMENT PARAMETERS)
      PRINT 445,LOCSV
  445 FORMAT (/,1H0,4X,24HXEQ007, EQUIPMENT NUMBER,I3)
      SVI241=SV(LIS2,41)*0.015852/RHOH20
      SV0141=SV(LOS1,41)*0.015852/RHOH20
      SV0241=SV(LOS2,41)*0.015852/RHOH20
      PRINT 450,SVI241,SV0141,SV0241,RCYCLE
  450 FORMAT (6X,23HWATER TREATMENT RATE = ,F7.0,4H GPM,/,1H ,5X,
     *          23HRETURN WATER RATE     = ,F7.0,4H GPM,/,1H ,5X,
     *          23HSLUDGE BLOWDOWN RATE = ,F7.0,4H GPM,/,1H ,5X,
     *          23HSLUDGE RECYCLE RATE  = ,F7.0,4H GPM)
      CAOH2=CAOH2*XMW(26)/XLIM(1)/453.6*3600.0
      NA2CO3=NA2CO3*XMW(37)/XSOD(1)/453.6*3600.0
      MGOH2=MGOH2*XMW(31)/XMGSS(1)/453.6*3600.0
      PRINT 460,CAOH2,NA2CO3,MGOH2
  460 FORMAT (6X,42HCHEMICAL ADDITION RATES ACCORDING TO USER ,
     *          32HSPECIFIED STOICHIOMETRIC FACTORS,/,1H ,9X,9HLIME      ,
     *          2H= ,F5.0,6H LB/HR,/,1H ,9X,11HSODA ASH = ,F5.0,6H LB/HR,
     *          /,1H ,9X,11HMG(OH)2  = ,F5.0,6H LB/HR)
      PRINT 470,RVM3,RVFT3,RVGAL
  470 FORMAT(/,1H ,5X,17HREACTOR VOLUME = ,F5.0,16H CUBIC METERS ; ,
     *         F7.0,14H CUBIC FEET ; ,F8.0,5H GAL.)
      PRINT 480,ACID
  480 FORMAT(6X,12HACID RATE = ,F5.0,6H LB/HR)
      RETURN
  488 CONTINUE
      KCOUNT=0
      DO 490 I=1,130
      SV(LDS1,I)=0.0
      SV(LDS2,I)=0.0
      SV(LDS3,I)=0.0
  490 CONTINUE
      DO 500 I=1,13
      SOLIDS(I)=0.0
      TEST3(I)=0.0
  500 CONTINUE
      RETURN
  550 CONTINUE
      SV(LIS1,41)=0.0
      SV(LOS1,41)=0.0
      SV(LOS2,41)=0.0
      SV(LIS1,118)=0.0
      SV(LOS1,118)=0.0
      SV(LOS2,118)=0.0
      K1=0
      K2=0
      CALL XSE003(K1,K2)
      RETURN
      END

@PRT,S    X.XEQ008/
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390-1514*ASH(1).XEQ008(45)

```
      COMPILER (STD=66)
      SUBROUTINE XEQU08(P)
C
C
C
C
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C
      DOUBLE PRECISION LABEL,IDEQP
      COMMON/CMMN/SV(25,130),IDEQP(20),ISTM(25,10),ISEQ(25),PA(20,24),
     *           L(2),NL,LSPL(2),LERL(2),WV,DNAT(4),XA(4),LABEL(13),
     *           AH2O
      COMMON/FLAG/IFLAG
      COMMON/SUMMR/RSCAS
      COMMON/DEBUG/IPT
      DIMENSION P(1)
      DIMENSION IOPT(34),PP(4)
      DATA IOPT/34*0/,PP/4*0.0/
      LOCSV=ISEQ(NL)
      LIS1=ISTM(LOCSV,1)
      LIS2=ISTM(LOCSV,2)
      LIS3=ISTM(LOCSV,3)
      LIS4=ISTM(LOCSV,4)
      LOS =ISTM(LOCSV,6)
      IF(SV(LOS,2).GT.0.5) GO TO 1
      RETURN
    1 CONTINUE
      SV(LOS,6)=SV(LIS2,6)
      CALL XSE001(LIS1,LIS2,LIS3,LIS4,LOS)
      IF(ISEQ(NL).NE.13) GO TO 10
      SAVEIN=SV(LOS,32)
      IFLAG=1
      IOPT(19)=1
      NS=1
      CALL YEQ001(LOS,IOPT,SV(LOS,5),PP,WNES,NS)
      NS=0
      RSCAS=SV(LOS,100)
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                SV(LOS,32)=SAVEIN
                SV(LOS,118)=SV(LOS,32)
             10 CONTINUE
                K2=0
                K3=0
                CALL XSE003(K2,K3)
                IF(IPT.EQ.1) CALL XSE006(LIS1)
                IF(IPT.EQ.1) CALL XSE006(LIS2)
                IF(IPT.EQ.1) CALL XSE006(LIS3)
                IF(IPT.EQ.1) CALL XSE006(LIS4)
                IF(IPT.EQ.1) CALL XSE006(LOS)
                RETURN
                END

@PRT,S     X.XEQ009/
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                                                                                   DATE 113084

390-1514*ASH(1).XEQ009(59)
              COMPILER (STD=66)
              SUBROUTINE XEQ009(P)
      C
      C
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      C
      C
      C
      C
      C
              DOUBLE PRECISION LABEL,IDEQP
              COMMON/CMMN/SV(25,130),IDEQP(20),ISTM(25,10),ISEQ(25),PA(20,24),
             *        L(2),NL,LSRL(2),LERL(2),WV,DNAT(4),XA(4),LABEL(13),
             *        AH20
              COMMON/DEBUG/IPT
              COMMON/BD/XINERT
              COMMON/ASHCOM/ASHFLO,XASH(7)
              DIMENSION P(1)
              INTEGER OPN
      C
      C
      C
      C
      C
              LOCSV=ISEG(NL)
              LIS1=ISTM(LOCSV,1)
              LOS1=ISTM(LOCSV,6)
              LOS2=ISTM(LOCSV,7)
              IF(SV(LIS1,2).GT.1.5) RETURN
              IF(SV(LIS1,2).GT.0.5) GO TO 25
              ICOUNT=1
              RETURN
           25 CONTINUE
      C
      C
      C
              IF(ISEQ(NL).EQ.8) GO TO 70
      C
      C
      C
      C
              SV(LOS1,5)=SV(LIS1,5)
      SV(LOS2,5)=SV(LIS1,5)
      SV(LOS1,6)=SV(LIS1,6)
      SV(LOS2,6)=SV(LIS1,6)
      SV(LOS1,19)=SV(LIS1,19)
      SV(LOS2,19)=SV(LIS1,19)
      DO 35 I=1,3
      SV(LOS1,I+37)=SV(LIS1,I+37)
      SV(LOS2,I+37)=SV(LIS1,I+37)
   35 CONTINUE
      DO 40 I=1,6
      SV(LOS1,I+99)=SV(LIS1,I+99)
      SV(LOS2,I+99)=SV(LIS1,I+99)
   40 CONTINUE
C
C
C
      DO 45 I=1,47
      SV(LOS1,I+41)=SV(LIS1,I+41)
      SV(LOS2,I+41)=SV(LIS1,I+41)
   45 CONTINUE
C
C
C
      SV(LOS2,41)=SV(LIS1,41)-SV(LOS1,41)
      DO 60 I=1,13
      SV(LOS1,I+105)=SV(LIS1,I+105)*SV(LOS1,41)/SV(LIS1,41)
      SV(LOS2,I+105)=SV(LIS1,I+105)-SV(LOS1,I+105)
   60 CONTINUE
      OPN=3
      CALL XSE008 (LOS1,OPN)
      CALL XSE008 (LOS2,OPN)
      K1=0
      K2=0
      CALL XSE003(K1,K2)
      IF(IPT.EQ.1) CALL XSE006(LIS1)
      IF(IPT.EQ.1) CALL XSE006(LOS1)
      IF(IPT.EQ.1) CALL XSE006(LOS2)
      RETURN
   70 CONTINUE
C
C
C
C
```

```
      SV(LIS1,5)=SV(LOS1,5)
      SV(LOS2,5)=SV(LOS1,5)
      SV(LIS1,6)=SV(LOS1,6)
      SV(LOS2,6)=SV(LOS1,6)
      SV(LIS1,19)=SV(LOS1,19)
      SV(LOS2,19)=SV(LOS1,19)
      DO 80 I=1,3
      SV(LIS1,I+37)=SV(LOS1,I+37)
      SV(LOS2,I+37)=SV(LOS1,I+37)
   80 CONTINUE
      DO 85 I=1,6
      SV(LIS1,I+99)=SV(LOS1,I+99)
      SV(LOS2,I+99)=SV(LOS1,I+99)
   85 CONTINUE
C
C
C
      DO 90 I=1,47
      SV(LIS1,I+41)=SV(LOS1,I+41)
      SV(LOS2,I+41)=SV(LOS1,I+41)
   90 CONTINUE
C
C
C
      SV(LOS2,41)=SV(LIS1,41)-SV(LOS1,41)
      SV(LIS1,118)=(XINERT/100.)*SV(LIS1,41)
      SV(LIS1,32) = SV(LIS1,118)
      SV(LOS2,118) = SV(LIS1,118)-SV(LOS1,118)
      SV(LOS2,32) = SV(LOS2,118)
      OPN=3
      CALL XSE008 (LIS1,OPN)
      CALL XSE008 (LOS2,OPN)
      IF(SV(LOS1,41).LE.SV(LIS1,41)) GO TO 130
      PRINT 27, LOCSV, SV(LIS1,41), SV(LOS1,41)
   27 FORMAT(1H0,10X,43H***** FATAL ERROR IN XEQ009, EQUIPMENT NO. ,I2,
     *       6H *****,//,5X,41HEFFLUENT FLOWRATE EXCEEDS INLET FLOWRATE.,
     *       //,8X,20HINLET FLOWRATE    = ,E10.4,10H G H2O/SEC,/,
     *       8X,20HEFFLUENT FLOWRATE = ,E10.4,10H G H2O/SEC)
      CALL XSE006(LIS1)
      CALL XSE006(LOS1)
      STOP
  130 CONTINUE
      K1=0
```

```
                  K2=0
                  CALL XSE003(K1,K2)
                  IF(IPT.EQ.1) CALL XSE006(LIS1)
                  IF(IPT.EQ.1) CALL XSE006(LOS1)
                  IF(IPT.EQ.1) CALL XSE006(LOS2)
                  RETURN
                  END

@PRT,S     X.XEQ010/
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```
390-1514*ASH(1).XEQ010(40)
      COMPILER (STD=66)
      SUBROUTINE XEQ010(P)

C
C
C
      DOUBLE PRECISION LABEL,IDEQP
      COMMON/CMMN/SV(25,130),IDEQP(20),ISTM(25,10),ISEQ(25),PA(20,24),
     *           L(2),NL,LSRL(2),LERL(2),WV,DNAT(4),XA(4),LABEL(13),
     *           AH2O
      COMMON/FLAG/IFLAG
      COMMON/LCMN/XMW(100),DHF(100),ENTO(100),ACP(100),BCP(100),CCP(100)
     *           ,DCP(100),TMIN(100),TMAX(100),ZE(100),ALIT(100),
     *            BLIT(100),UCAP(100),SPGR(25)
      COMMON/PAGE/LINE
      COMMON/RESEN/REN
      COMMON/WTRIN/MUCONC(12),CONC(12)
      DIMENSION P(1)
      DIMENSION IOPT(34),XX(2),ER(2)
      LOCSL=ISEQ(NL)
      LOS=ISTM(LOCSL,6)
      IF(SV(LOS,2).GT.0.5)  RETURN
      LINE=LINE+12
      IF(LINE.LT.43)  GO TO 2
      LINE=12
      WRITE(6,1) LABEL
    1 FORMAT(1H1,1H+,35X,13A6,/,18H INPUT STREAM DATA)
    2 WRITE(6,3) LOCSL,P(16),P(1),P(14)
    3 FORMAT(/,5X,24HXEQ010, EQUIPMENT NUMBER,I3,/,6X,11HFLOWRATE = ,
     *F11.1,4H GPM,/,6X,14HTEMPERATURE = ,F6.1,6H DEG F,/,
     *6X,5HPH = ,F4.2)
      SV(LOS,5)=273.16+(P(1)-32.)/1.8
      SV(LOS,6)=1.
      DW=1000.*(0.9999528+0.4672661E-4*(SV(LOS,5)-273.16)-
     1           0.74105074E-5*(SV(LOS,5)-273.16)**2+
     2           0.41079583E-7*(SV(LOS,5)-273.16)**3-
     3           0.13370708E-9*(SV(LOS,5)-273.16)**4)
      SV(LOS,41)=P(16)*DW*3.785306/60.
      CONCT=0.
      DO 4 I=1,12
      CONC(I)=P(I+1)
    4 CONCT=CONCT+CONC(I)
      CONCT=CONCT/1000000.
      FACTOR=0.001/(1.-CONCT)
      DO 5 I=1,11
    5 SV(LOS,I+77)=CONC(I)*FACTOR/XMW(I+82)
      SV(LOS,87)=CONC(10)*FACTOR/XMW(35)
      SV(LOS,45)=CONC(7)*FACTOR/50.04
      ION=P(15)+0.01
      SV(LOS,40)=P(14)
C
      IF(ION.LE.0) ION=3
      K1=1
      CALL XSE008(LOS,K1)
      IOPT(1)=1
      IOPT(19)=1
      IFLAG=1
      NS=1
    6 CONTINUE
      CALL YEQ001(LOS,IOPT,SV(LOS,5),PP,WNES,NS)
      XX(2)=SV(LOS,ION+19)
      DO 11 I=1,10
      IF(ABS(REN).LT.1.E-6)  GO TO 12
      IF(I.NE.1) GO TO 7
      XX(1)=1.05*XX(2)
      ER(2)=REN
      GO TO 8
    7 DER=(ER(1)-ER(2))/(XX(1)-XX(2))
      XX(2)=XX(1)
      ER(2)=ER(1)
      XX(1)=XX(1)-ER(1)*DER/(DER*DER)
    8 SV(LOS,ION+19)=XX(1)
      IF(XX(1).GT.0.)GO TO 10
      WRITE(6,9)
    9 FORMAT(5X,48HTHE ION CHOSEN TO MINIMIZE ION IMBALANCE IS TOO,
     *       5HSMALL,/,5X,15HTRY ANOTHER ONE)
      STOP
C
   10 CONTINUE
      CALL YEQ001(LOS,IOPT,SV(LOS,5),PP,WNES,NS)
C
   11 ER(1)=REN
   12 XF=SV(LOS,ION+19)*1000000.0*XMW(ION+82)*(1.0-CONCT)/SV(LOS,41)
      TOTALK= 2.0*(SV(LOS,52)+SV(LOS,57)+SV(LOS,61)+SV(LOS,84))+
     1                 SV(LOS,43)+SV(LOS,45)+SV(LOS,50)+SV(LOS,51)+
     2                 SV(LOS,55)+SV(LOS,56)+SV(LOS,59)+SV(LOS,60)-
     3            SV(LOS,42)
      TOTALK=TOTALK*1000.*50.04*(1.-CONCT)
      TEST=(TOTALK-CONC(7))/CONC(7)
      IF(ABS(TEST).LE.0.01) GO TO 13
      SV(LOS,26)=SV(LOS,26)*CONC(7)/TOTALK
C
      GO TO 6
C
 13   WRITE(6,14)
 14   FORMAT(8X,3HION,8X,7HSPECIES,8X,18HCONCENTRATION, PPM,5X,3HION,10X
     *,7HSPECIES,10X,18HCONCENTRATION, PPM)
      WRITE(6,15)(CONC(I),CONC(I+6),I=1,6)
 15   FORMAT(8X,2H 1,4X,15HCALCIUM (AS CA),8X,F8.1,11X,1H7,4X,      21H
     1ALKALINITY (AS CACO3),8X,F8.1,/,
     2 9X,1H2,4X,17HMAGNESIUM (AS MG),6X,F8.1,11X,1H8,4X,
     3 16HNITRATE (AS NO3),13X,F8.1,/,
     4 9X,1H3,4X,14HSODIUM (AS NA),9X,F8.1,11X,1H9,4X,
     5 16HSULFATE (AS SO4),13X,F8.1,/,
     6 9X,1H4,4X,16HAMMONIA (AS NH4),7X,F8.1,11X,2H10,3X,
     7 16HSILICA (AS SIO2),13X,F8.1,/,
     8 9X,1H5,4X,16HPOTASSIUM (AS K),7X,F8.1,11X,2H11,3X,
     9 18HPHOSPHATE (AS PO4),11X,F8.1,/,
     A 9X,1H6,4X,16HCHLORIDE (AS CL),7X,F8.1,11X,2H12,3X,
     B 11HSUS. SOLIDS,18X,F8.1)
C
      CONC(ION)=XF
      WRITE(6,16) ION,XF
 16   FORMAT(/,9X,8HION NO. ,I2,13H ADJUSTED TO ,F8.1,30H PPM TO MINIMIZ
     *E ION IMBALANCE)
C
      RETURN
      END

@PRT,S     X.XEX001/
```

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                                                                      DATE 113084

390-1514*ASH(1).XEX001(53)
              COMPILER (STD=66)

      C
      C
      C
      C
      C
      C
      C
      C
            DOUBLE PRECISION LABEL,IDEQP
            COMMON/CMMN/SV(25,130),IDEQP(20),ISTM(25,10),ISEQ(25),PA(20,24),
     *                 L(2),NL,LSRL(2),LERL(2),WV,DNAT(4),XA(4),LABEL(13),
     *                 AH20
            COMMON/FLAGS/KTRT,KWW,KAC,KFIX,IOUT,IUNITS,ISV
            DO 2 I=1,25
            DO 1 J=1,130
            SV(I,J) = 0.
          1 CONTINUE
          2 CONTINUE
            CALL XEX002
            CALL XEX003
            CALL XEX004
            CALL XSE004 (IUNITS,IOUT)
            STOP
            END

@PRT,S     X.XEX002/
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                                                                    DATE 113084
390-1514*ASH(1).XEX002(12)
      COMPILER (STD=66)
      SUBROUTINE XEX002
C
C
C
C
C
C
C
C
C
C
C
      DOUBLE PRECISION LABEL,IDEQP
      COMMON/CMMN/SV(25,130),IDEQP(20),ISTM(25,10),ISEQ(25),PA(20,24),
     *            L(2),NL,LSRL(2),LERL(2),WV,DNAT(4),XA(4),LABEL(13),
     *            AH20
      COMMON/XXLP/XLOOP
      COMMON/DEBUG/IPT
      COMMON/FLAGS/KTRT,KWW,KAC,KFIX,IOUT,IUNITS,ISV
      COMMON/STRMS/ISTM1(15,10),ISTMX(15,10),IORDR1(8,33),IORDR2(8,33),
     *             NSV(25)
      DIMENSION IORDER(32),PTEMP(8)
      DOUBLE PRECISION NAME(11)
      DATA NAME/6HXEQ002,6HXEQ004,6HXEQ003,6HXEQ010,6HXEQ005,6HXEQ001,
     *          6HXEQ009,6HXEQ007,6HXEQ008,6HXEQ006,6H      /
      DATA PA/480*0./
      IORD=1
    1 GO TO (5,10,80,210,290), IORD
C
C
C
    5 READ 300, LABEL
      PRINT 301
      PRINT 302,LABEL
      IORD=2
      GO TO 1
C
C
C
   10 CONTINUE
      READ 304,KTRT,KWW,KAC,KFIX,IOUT,IUNITS,ISV,IPT,XLOOP
```

```
C
C
C
      GO TO (20,25,20,20,25,25,20,25),KTRT
   20 CONTINUE
      IF (KAC.GT.0) KAC=0
      IF (KTRT.EQ.1.OR.KTRT.EQ.4) GO TO 30
      GO TO 35
   25 CONTINUE
      IF (KAC.LE.0.OR.KAC.GE.4) KAC=1
      IF (KTRT.EQ.5.OR.KTRT.EQ.8) GO TO 35
   30 CONTINUE
      IF (KFIX.NE.1) KFIX=1
   35 CONTINUE
      IF (KWW.NE.2) KWW=1
C
C
C
      DO 46 I=1,3
      IDEQP(I)=NAME(I)
   46 CONTINUE
      IF (KTRT.EQ.1.OR.KTRT.EQ.3.OR.KTRT.EQ.4.OR.KTRT.EQ.7) IDEQP(3)=
     *    NAME(11)
      IDEQP(4)=NAME(3)
      IF (KTRT.EQ.1.OR.KTRT.EQ.2.OR.KTRT.EQ.4.OR.KTRT.EQ.6) IDEQP(4)=
     *    NAME(11)
      DO 50 I=1,4
      IDEQP(I+4)=NAME(I+3)
   50 CONTINUE
      IF (KWW.NE.2) IDEQP(5)=NAME(11)
      IDEQP(9)=NAME(7)
      IDEQP(10)=NAME(8)
      IDEQP(11)=NAME(9)
      IF (KTRT.EQ.3.OR.KTRT.EQ.5.OR.KTRT.GE.7) GO TO 54
      IDEQP(9)=NAME(11)
      IDEQP(10)=NAME(11)
      IDEQP(11)=NAME(11)
   54 CONTINUE
      IDEQP(12)=NAME(9)
      IDEQP(13)=NAME(9)
      IDEQP(14)=NAME(10)
      IF (KTRT.LE.3.OR.KTRT.EQ.5) IDEQP(14)=NAME(11)
      IDEQP(15)=NAME(9)
      IF (KTRT.EQ.1.OR.KTRT.EQ.3.OR.KTRT.EQ.4.OR.KTRT.EQ.7)
     *   IDEQP(15)=NAME(11)
C
C
C
      DO 58 I=1,25
      DO 57 J=1,10
      ISTM(I,J)=ISTM1(I,J)
   57 CONTINUE
   58 CONTINUE
      DO 63 I=1,10
      IF(KWW.EQ.1) GO TO 59
      ISTM(6,I)=ISTMX(1,I)
      IF(IDEQP(14).EQ.NAME(10)) ISTM(6,I)=ISTMX(2,I)
      IF(IDEQP(15).EQ.NAME(9)) ISTM(6,I)=ISTMY(3,I)
      IF(IDEQP(14).EQ.NAME(10).AND.IDEQP(15).EQ.NAME(9))
     *   ISTM(6,I)=ISTMX(4,I)
      GO TO 60
   59 CONTINUE
      IF(IDEQP(14).EQ.NAME(10)) ISTM(6,I)=ISTMX(5,I)
      IF(IDEQP(15).EQ.NAME(9)) ISTM(6,I)=ISTMX(6,I)
      IF(IDEQP(14).EQ.NAME(10).AND.IDEQP(15).EQ.NAME(9))
     *   ISTM(6,I)=ISTMX(7,I)
   60 CONTINUE
      IF(KWW.EQ.2) GO TO 61
      IF(KTRT.EQ.1.OR.KTRT.EQ.4) GO TO 62
      IF(KTRT.EQ.2.OR.KTRT.EQ.6) ISTM(7,I)=ISTMX(8,I)
      IF(KTRT.EQ.3.OR.KTRT.EQ.7) ISTM(7,I)=ISTMX(9,I)
      IF(KTRT.EQ.5.OR.KTRT.EQ.8) ISTM(7,I)=ISTMX(10,I)
      GO TO 62
   61 CONTINUE
      ISTM(7,I)=ISTMX(11,I)
      IF(KTRT.EQ.1.OR.KTRT.EQ.4) GO TO 62
      IF(KTRT.EQ.2.OR.KTRT.EQ.6) ISTM(7,I)=ISTMX(12,I)
      IF(KTRT.EQ.3.OR.KTRT.EQ.7) ISTM(7,I)=ISTMX(13,I)
      IF(KTRT.EQ.5.OR.KTRT.EQ.8) ISTM(7,I)=ISTMX(14,I)
   62 CONTINUE
      IF (IDEQP(11).EQ.NAME(9)) ISTM(12,I)=ISTMX(15,I)
   63 CONTINUE
      DO 66 I=1,15
      IF (IDEQP(I).NE.NAME(11)) GO TO 66
      DO 64 J=1,10
      ISTM(I,J)=0
   64 CONTINUE
   66 CONTINUE
C
C
C
      PRINT 303
      DO 70 I=1,15
      PRINT 307,I,IDEQP(I),(ISTM(I,J),J=1,10)
   70 CONTINUE
      IORD=IORD+1
      GO TO 1
C
C
C
   80 CONTINUE
      NLP=0
      NC=0
      IC=1
      LW=0
      LE=0
      IF (KWW.EQ.2) GO TO 90
      DO 85 I=1,32
      IORDER(I)=IORDR1(KTRT,I+1)
   85 CONTINUE
      KTRT1=0
      GO TO 100
   90 CONTINUE
      KTRT1=KTRT
      DO 95 I=1,32
      IORDER(I)=IORDR2(KTRT,I+1)
   95 CONTINUE
  100 CONTINUE
      PRINT 308
      KPRINT=(IORDR1(KTRT,1)-14)/2
      IF (KTRT1.GT.0) KPRINT=(IORDR2(KTRT,1)-14)/2
      IF (KPRINT.EQ.1) PRINT 310,IORDER
      IF (KPRINT.EQ.2) PRINT 312,IORDER
      IF (KPRINT.EQ.3) PRINT 314,IORDER
      IF (KPRINT.EQ.4) PRINT 316,IORDER
      IF (KPRINT.EQ.5) PRINT 318,IORDER
      IF (KPRINT.EQ.6) PRINT 320,IORDER
      IF (KPRINT.EQ.7) PRINT 322,IORDER
      IF (KPRINT.EQ.8) PRINT 324,IORDER
      IF (KPRINT.EQ.9) PRINT 326,IORDER
C
C
C
      KSEQ=(IORDR1(KTRT,1))/2
      IF (KTRT1.GT.0) KSEQ=(IORDR2(KTRT,1))/2
      DO 150 I=1,KSEQ
      II=2*I-1
      ISEQ(I)=IORDER(II)
      IF (ISEQ(I).EQ.8) LSRL(1)=I
      IF (ISEQ(I).EQ.7) LERL(1)=I
  150 CONTINUE
      ISEQ(KSEQ+1)=0
      PRINT 330,ISEQ(LSRL(1)),ISEQ(LERL(1))
      IF (KTRT.EQ.1) PRINT 335
      IF (KTPT.EQ.2) PRINT 336
      IF (KTRT.EQ.3) PRINT 337
      IF (KTRT.EQ.4) PRINT 338
      IF (KTRT.EQ.5) PRINT 339
      IF (KTRT.EQ.6) PRINT 340
      IF (KTRT.EQ.7) PRINT 341
      IF (KTRT.EQ.8) PRINT 342
      IF (KWW.EQ.1) PRINT 345
      IF (KWW.EQ.2) PRINT 346
      IF (KTRT.EQ.1.OR.KTRT.EQ.3.OR.KTPT.EQ.4.OR.KTRT.EQ.7) GO TO 180
      IF (KAC.EQ.1) PRINT 350
      IF (KAC.EQ.2) PRINT 351
      IF (KAC.EQ.3) PRINT 352
  180 CONTINUE
      IF (KTRT.LE.2.OR.KTRT.EQ.4.OR.KTRT.EQ.6) GO TO 182
      IF (KFIX.EQ.1) PRINT 356
      IF (KFIX.EQ.2) PRINT 357
  182 CONTINUE
      IORD=IORD+1
      GO TO 1
C
C
C
  210 CONTINUE
      READ(5,370) NUM,PTEMP
      IF (NUM.EQ.0) GO TO 220
      IF (NUM.EQ.99) GO TO 230
      NC=1
      DO 215 I=1,8
      PA(NUM,I)=PTEMP(I)
  215 CONTINUE
      NUMSAV=NUM
      GO TO 210
  220 CONTINUE
      NUM=NUMSAV
      DO 225 I=1,8
      IN=8*NC+I
      PA(NUM,IN)=PTEMP(I)
  225 CONTINUE
      NC=NC+1
      GO TO 210
  230 CONTINUE
      IF (ISV.NE.2) GO TO 240
      READ (5,372) NSV
  240 CONTINUE
      IORD=IORD+1
      GO TO 1
  290 CONTINUE
      RETURN
C
C
C
  300 FORMAT(13A6)
  301 FORMAT(1H1)
  302 FORMAT(10X,13A6)
  303 FORMAT(/,25X,20H PROCESS DESCRIPTION,/,/,11H  EQUIP.NO.,5X,
     *       11H EQUIP.NAME,5X,14H INPUT STREAMS,9X,15H OUTPUT STREAMS,/)
 304  FORMAT(8I1,F8.3)
  307 FORMAT(I6,12X,A6,3X,5I4,3X,5I4)
  308 FORMAT(/,/,20X,30H ORDER OF PROCESS CALCULATIONS)
  310 FORMAT(/,10X,8(I2,A1),16A1)
  312 FORMAT(/,10X,9(I2,A1),14A1)
  314 FORMAT(/,10X,10(I2,A1),12A1)
  316 FORMAT(/,10X,11(I2,A1),10A1)
  318 FORMAT(/,10X,12(I2,A1),8A1)
  320 FORMAT(/,10X,13(I2,A1),6A1)
  322 FORMAT(/,10X,14(I2,A1),4A1)
  324 FORMAT(/,10X,15(I2,A1),2A1)
  326 FORMAT(/,10X,16(I2,A1))
  330 FORMAT(/,10X,18H RECYCLE LOOP FROM,I3,3H TO,I3)
  335 FORMAT(/,10X,23H NO TREATMENT SPECIFIED)
  336 FORMAT(/,10X,28H ACID/CAUSTIC TREATMENT ONLY)
  337 FORMAT(/,10X,26H SIDESTREAM SOFTENER  ONLY)
  338 FORMAT(/,10X,24H REACTION/HOLD TANK ONLY)
  339 FORMAT(/,10X,49H ACID/CAUSTIC TREATMENT WITH SIDESTREAM SOFTENER )
  340 FORMAT(/,10X,47H ACID/CAUSTIC TREATMENT WITH REACTION/HOLD TANK)
  341 FORMAT(/,10X,45H SIDESTREAM SOFTENER  WITH REACTION/HOLD TANK)
  342 FORMAT(/,10X,49H ACID/CAUSTIC TREATMENT WITH SIDESTREAM SOFTENER ,
     *       23H AND REACTION/HOLD TANK)
  345 FORMAT(/,10X,48H NO WASTEWATER ADDED TO POND FROM OUTSIDE SOURCE)
  346 FORMAT(/,10X,45H WASTEWATER ADDED TO POND FROM OUTSIDE SOURCE)
  350 FORMAT(/,10X,49H ACID/CAUSTIC TREATMENT BASED ON CACO3 SATURATION)
  351 FORMAT(/,10X,43H ACID/CAUSTIC TREATMENT BASED ON ALKALINITY)
  352 FORMAT(/,10X,35H ACID/CAUSTIC TREATMENT BASED ON PH)
  356 FORMAT(/,10X,36H SIDESTREAM TREATMENT RATE NOT FIXED)
  357 FORMAT(/,10X,32H SIDESTREAM TREATMENT RATE FIXED)
  370 FORMAT(I2,F8.3,7F10.3)
  372 FORMAT(25I3)
      END

@PRT,S     X.XEX003/
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```
39U-1514*ASH(1).XEX003(53)
      COMPILER (STD=66)
      SUBROUTINE XEX003
C
C
C
C
C
C
      INTEGER XEX005
      DOUBLE PRECISION LABEL,IDEQP,NAME
      COMMON/CMMN/SV(25,130),IDEQP(20),ISTM(25,10),ISEQ(25),PA(20,24),
     *            L(2),NL,LSRL(2),LERL(2),WV,DNAT(4),XA(4),LABEL(13),
     *            AH20
      COMMON/PAGE/LINE
      IFL = 0
    5 IFL=IFL+1
      LINE = 50
      DO 25 J=1,25
      I=ISEQ(J)
      JM1= J-1
      IF(JM1.LE.0) GO TO 15
      DO 10 K=1,JM1
      IF(I.EQ.ISEQ(K)) GO TO 25
   10 CONTINUE
   15 CONTINUE
      NL=J
      IF(I.EQ.0) GO TO (5,30),IFL
      IF(ISTM(I,1).EQ.0) GO TO (20,25),IFL
      GO TO (25,20),IFL
   20 NAME=IDEQP(I)
      IN=XEX005(NAME)
      CALL XEX006(IN,I)
   25 CONTINUE
      GO TO (5,30),IFL
   30 DO 35 J=1,25
      SV(J,2)=1
   35 CONTINUE
      RETURN
      END

@PRT,S     X.XEX004/
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                                                                                 DATE 113084
390-1514*ASH(1).XEX004(50)
      COMPILER (STD=66)
      SUBROUTINE XEX004
C
C
      INTEGER XEX005
      DOUBLE PRECISION LABEL,IDEQP,NAME
      COMMON/CMMN/SV(25,130),IDEQP(20),ISTM(25,10),ISEQ(25),PA(20,24),
     *            L(2),NL,LSRL(2),LERL(2),WV,DNAT(4),XA(4),LABEL(13),
     *            AH20
C
C
C
      L(1)=0
      ICOUNT = 0
      I=0
    5 I=I+1
      IF(ISEQ(I).EQ.0) RETURN
      DO 20 J=1,2
      IF(I.EQ.LSRL(J)) GO TO 10
      GO TO 20
   10 JP1=J+1
      DO 15 JP=JP1,2
      L(JP)=0
   15 CONTINUE
   20 CONTINUE
      NEXN=ISEQ(I)
      NAME=IDEQP(NEXN)
      NEIN=XEX005(NAME)
      NL=I
      CALL XEX006(NEIN,NEXN)
   25 CONTINUE
      I=NL
      DO 30 JD=1,2
      J = 3 - JD
      IF(I.EQ.LERL(J).AND.L(J).EQ.0) GO TO 35
   30 CONTINUE
      GO TO 5
   35 I=LSRL(J)-1
      CALL XC0004(J)
      IF(L(J).EQ.1) GO TO 25
      GO TO 5
      END
```

```
@PRT,S    X.XEX005/                                        DATE 113084
```

```
390-1514*ASH(1).XEX005(51)
              COMPILER (STD=66)
              INTEGER FUNCTION XEX005(NAME)
        C
        C
        C
              DOUBLE PRECISION NAME,ILAB(11)
              DATA ILAB/6HXEQ002,6HXEQ004,6HXEQ003,6HXEQ010,6HXEQ005,6HXEQ001,
             *          6HXEQ009,6HXEQ007,6HXEQ008,6HXEQ006,6H      /
        C
              DO 10 XEX005=1,11
         10   IF (ILAB(XEX005) .EQ. NAME) RETURN
              PRINT 20, NAME
           20 FORMAT(1H1,////////,8X,23H***** FATAL ERROR *****,A6,//,5X,
             *       50HUSER HAS REQUESTED AN EQUIPMENT NAME NOT LISTED IN,
             *       7H XEX005)
              STOP
              END

@PRT,S    X.XEX006/
```

```
59U-1514*ASH(1).XEXQ06(45)
      COMPILER (STD=66)
      SUBROUTINE XEXQ06 (IN,IX)
C
C
C
C
C
      DOUBLE PRECISION LABEL,IDEQP
      COMMON/CMMN/SV(25,130),IDEQP(20),ISTM(25,10),ISEQ(25),PA(20,24),
     *            L(2),NL,LSRL(2),LERL(2),WV,DNAT(4),XA(4),LABEL(13),
     *            AH20
      DIMENSION P(24)
      DO 90 I=1,24
   90 P(I) = PA(IX,I)
      GO TO (1,2,3,4,5,6,7,8,9,10,11), IN
    1 CALL XEQ002(P)
      GO TO 100
    2 CALL XEQ004(P)
      GO TO 100
    3 CALL XEQ003(P)
      GO TO 100
    4 CALL XEQ010(P)
      GO TO 100
    5 CALL XEQ005(P)
      GO TO 100
    6 CALL XEQ001(P)
      GO TO 100
    7 CALL XEQ009(P)
      GO TO 100
    8 CALL XEQ007(P)
      GO TO 100
    9 CALL XEQ008(P)
      GO TO 100
   10 CALL XEQ006(P)
      GO TO 100
   11 CONTINUE
  100 RETURN
      END

@PRT,S     X.XSE001/
```

```
                                                                   DATE 113084
39U-1514*ASH(1).XSE001(45)
            COMPILER (STD=66)
            SUBROUTINE XSE001 (L1, L2, L3, L4, L0)
      C
      C
      C
      C
      C
      C
            DOUBLE PRECISION LABEL,IDEQP
            COMMON/CMMN/SV(25,130),IDEQP(20),ISTM(25,10),ISEQ(25),PA(20,24),
           *            L(2),NL,LSRL(2),LERL(2),WV,DNAT(4),XA(4),LABEL(13),
           *            AH20
      C
            SV(L0,5) = SV(L2,5)
            IF (SV(L0,5) .LE. 0.) SV(L0,5) = SV(L1,5)
            SV(L0,6) = AMIN1 (SV(L1,6), SV(L2,6), SV(L3,6), SV(L4,6))
            DO 10 I=10,14
         10 SV(L0,I) = SV(L1,I)+SV(L2,I)+SV(L3,I)+SV(L4,I)
            DO 20 I=20,32
         20 SV(L0,I) = SV(L1,I)+SV(L2,I)+SV(L3,I)+SV(L4,I)
            SV(L0,41) = SV(L1,41)+SV(L2,41)+SV(L3,41)+SV(L4,41)
            DO 30 I = 106,118
         30 SV(L0,I) = SV(L1,I)+SV(L2,I)+SV(L3,I)+SV(L4,I)
            DO 40 I=38,88
            IF(I.EQ.41) GO TO 40
            SV(L0,I) = (SV(L1,I)*SV(L1,41)+SV(L2,I)*SV(L2,41)+SV(L3,I)*SV(L3,
           * 41)+SV(L4,I)*SV(L4,41))/SV(L0,41)
         40 CONTINUE
            SV(L0,19) = (SV(L1,19)*SV(L1,41)+SV(L2,19)*SV(L2,41)+SV(L3,19)*
           * SV(L3,41)+SV(L4,19)*SV(L4,41))/SV(L0,41)
            DO 50 I=100,102
         50 SV(L0,I) = (SV(L1,I)*SV(L1,41)+SV(L2,I)*SV(L2,41)+SV(L3,I)*SV(L3,
           * 41)+SV(L4,I)*SV(L4,41))/SV(L0,41)
            RETURN
            END

@PRT,S     X.XSE002/
```

```
            COMPILER (STD=66)
            SUBROUTINE XSE002
      C
      C
      C
      C
      C
            COMMON/ADDIT/XACID,XCAU,RHOA,RHOC
            COMMON/ASHCOM/ASHFLO,XASH(7)
      C
      C
      C
            DOUBLE PRECISION LABEL,IDEQP
            COMMON/CMMN/SV(25,130),IDEQP(20),ISTM(25,10),ISEQ(25),PA(20,24),
           *         L(2),NL,LSRL(2),LERL(2),WV,DNAT(4),XA(4),LABEL(13),
           *         AH2O
            COMMON/FLAGS/KTRT,KWW,KAC,KFIX,IOUT,IUNITS,ISV
            COMMON/LCMN/XMW(100),DHF(100),ENTO(100),ACP(100),BCP(100),CCP(100)
           *         ,DCP(100),TMIN(100),TMAX(100),ZE(100),ALIT(100),
           *         BLIT(100),UCAP(100),SPGR(25)
            DOUBLE PRECISION KLG(46)
            DIMENSION PNT(6,16)
            INTEGER OPN
            DATA KLG/6HCA    ,6HMG    ,6HNA    ,6HNH4   ,6HK     ,6HCL    ,
           *        6HALK   ,6HNO3   ,6HSO4   ,6HSIO2  ,6HPO4   ,6HINERTS,
           *        6HFLOW (,6HGPM)  ,6HPH    ,6HCA(OH),6HCACO3 ,6HCA3(PO,
           *        6HCASO4(,6HCASO4.,6HMG(OH),6HMGCO3.,6HSEPIOL,6HCAH2SI,
           *        6HSIO2  ,6HCAHPO4,6HNA2CO3,6HINERTS,6H2     ,6H      ,
           *        6H4)2   ,6HANH)  ,6H2H2O  ,6H2     ,6H2H2O  ,6HITE   ,
           *        6HO4    ,4*6H    ,6HLB/HR),6HRS CAC,6HO3    ,
           *        6HRS GYP,6HSUM   /
            DL(T) = .99995282 + .46726616E-4*(T-273.16)
            1                 - .74105074E-5*(T-273.16)**2
            2                 + .41079583E-7*(T-273.16)**3
            3                 - .13370708E-9*(T-273.16)**4
            DO 1 I=1,6
            DO 1 J=1,16
          1 PNT(I,J)=0.
      C
      C
      C
            IACADD=0
      IRTANK=0
      ISOFT=0
      IF(KTRT.EQ.2.OR.KTRT.EQ.5.OR.KTRT.EQ.6.OR.KTRT.EQ.8) IACADD=1
      IF(KTRT.EQ.4.OR.KTRT.GE.6) IRTANK=1
      IF(KTRT.EQ.3.OR.KTRT.EQ.5.OR.KTRT.GE.8) ISOFT=1
C
      CALL XSE008(2,1)
      IF(KWW.EQ.1) CALL XSE008(5,1)
      IF(IACADD.EQ.1) CALL XSE008(3,1)
      CALL XSE008(8,1)
      IF(ISOFT.EQ.1) CALL XSE008(9,1)
C
C
C
C
      DO 60 I=1,6
      IF(KWW.NE.2.AND.I.EQ.2) GO TO 60
      IF(IACADD.EQ.0.AND.I.EQ.3) GO TO 60
      IF(ISOFT.EQ.0.AND.I.EQ.6) GO TO 60
      IF(I-3) 15,20,25
   15 CONTINUE
      LSV=2
      IF(I.EQ.2) LSV=5
      GO TO 30
   20 CONTINUE
      LSV=3
      GO TO 30
   25 CONTINUE
      LSV=7
      IF(I.EQ.5) LSV=8
      IF(I.EQ.6) LSV=9
   30 CONTINUE
      KW=3
      WT=XSE009(LSV,KW)
      IF(WT.LE.0.0) GO TO 60
      OPN=1
      CALL XSE008(LSV,OPN)
      DO 40 J=1,11
      PNT(I,J)=SV(LSV,J+19)*XMW(J+82)/WT*1000000.0
   40 CONTINUE
      TOTALK=2*(SV(LSV,52)+SV(LSV,57)+SV(LSV,61)+
     *        SV(LSV,84))+SV(LSV,45)+SV(LSV,51)+SV(LSV,56)+SV(LSV,60)+
     *        SV(LSV,43)+SV(LSV,50)+SV(LSV,55)+SV(LSV,59)-SV(LSV,42)
```

```
      PNT(I,7)=TOTALK*(SV(LSV,41)/1000.0)*XMW(57)/2.0/WT*1000000.0
      PNT(I,12)=SV(LSV,32)*XMW(38)/WT*1000000.0
      IF(DL(SV(LSV,5)).LE.0.0) GO TO 45
      PNT(I,13)=SV(LSV,41)/DL(SV(LSV,5))/3785.43*60.0
   45 CONTINUE
      PNT(I,14)=SV(LSV,40)
   60 CONTINUE
C
C
C
C
      IF(PNT(3,13).GT.0.0.AND.PNT(3,9).GT.0.0) PNT(3,13)=
     *   SV(3,28)*98.*1.83/3785.43*60.+PNT(3,13)
      IF(PNT(3,13).GT.0.0.AND.PNT(3,6).GT.0.0) PNT(3,13)=
     *   SV(3,25)*36.45/3785.43*60.+PNT(3,13)
      PNT(3,7)=0.0
C
      PNT(1,15)=SV(2,101)
      PNT(1,16)=SV(2,100)
      PNT(2,15)=SV(5,101)
      PNT(2,16)=SV(5,100)
      PNT(4,15)=SV(7,101)
      PNT(4,16)=SV(7,100)
      PNT(5,15)=SV(8,101)
      PNT(5,16)=SV(8,100)
C
C
C
      WRITE(6,100)
  100 FORMAT(1H1,28X,41HSUMMARY OF RECIRCULATING ASH SLUICE WATER,
     *        10H OPERATION,//,26X,13HLIQUID INPUTS,35X,
     *        14HLIQUID OUTPUTS,/,6X,53(1H*),4X,38(1H*),/,7X,
     *        9HCOMPONENT,5X,6HMAKEUP,5X,10HADDITIONAL,4X,
     *        12HACID/CAUSTIC,8X,4HPOND,7X,6HSYSTEM,5X,8HSOFTENER,/,
     *        9X,5H(PPM),8X,5HWATER,5X,10HWASTEWATER,6X,8HADDITION,
     *        9X,6HSLUDGE,5X,8HBLOWDOWN,5X,6HSLUDGE,/)
      DO 120 I=1,12
      WRITE(6,110) KLG(I),(PNT(J,I),J=1,6)
  110 FORMAT(8X,A6,6X,F8.1,5X,F8.1,7X,F8.1,8X,F8.1,4X,F8.1,4X,F8.1)
  120 CONTINUE
      WRITE(6,130) KLG(13),KLG(14),(PNT(J,13),J=1,6)
  130 FORMAT(8X,A6,A6,F8.1,5X,F8.1,7X,F8.3,8X,F8.1,4X,F8.1,4X,F8.1)
      WRITE(6,135) KLG(15),(PNT(J,14),J=1,6)
  135 FORMAT(8X,A6,10X,F4.1,9X,F4.1,11X,F4.1,12X,F4.1,8X,F4.1,8X,F4.1)
      WRITE(6,140) KLG(43),KLG(44),PNT(1,15),PNT(2,15),PNT(4,15),
     *          PNT(5,15)
  140 FORMAT(8X,A6,A6,F8.2,5X,F8.2,23X,F8.2,5X,F8.2)
      WRITE(6,140) KLG(45),KLG(46),PNT(1,16),PNT(2,16),PNT(4,16),
     *          PNT(5,16)
      WRITE(6,150) SV(18,100),SV(18,101)
  150 FORMAT(8X,33HRS GYPSUM IN ASH SLURRY STREAM = ,F6.2,
     *     /,8X,32HRS CACO3 IN ASH SLURRY STREAM = ,F7.2)
C
C
C
      DO 210 I=1,5
      DO 205 J=1,15
      PNT(I,J)=0.0
  205 CONTINUE
  210 CONTINUE
      DO 220 I=1,3
      II=I+4
      IF(I.EQ.3) II=8
      PNT(1,I)=XASH(I)
      PNT(1,II)=XASH(I+3)
  220 CONTINUE
      PNT(1,11)=XASH(7)
      PNT(1,12)=ASHFLO*3600.0/453.56
      PNT(1,9)=SV(1,29)*XMW(35)/ASHFLO*100.
      DO 275 I=2,4
      SUM=0.0
      IF(ISOFT.EQ.0.AND.I.EQ.2)  GO TO 275
      IF(ISOFT.EQ.0.AND.I.EQ.4)  GO TO 275
      IF(I-3) 230,235,240
  230 CONTINUE
      LSV=4
      GO TO 250
  235 CONTINUE
      LSV=7
      GO TO 250
  240 CONTINUE
      LSV=9
  250 CONTINUE
      KW=5
      WT=XSE009(LSV,KW)
      IF(WT.LE.0.0) GO TO 275
      DO 260 J=1,13
      PNT(I,J)=SV(LSV,J+105)*XMW(J+25)/WT*100.0
      SUM=SUM+SV(LSV,J+105)*XMW(J+25)
  260 CONTINUE
      PNT(I,14)=SUM/453.56*3600.0
  275 CONTINUE
C
C
C
      WRITE(6,300)
  300 FORMAT(/,33X,12HSOLID INPUTS,29X,13HSOLID OUTPUTS,/,15X,49(1H*),
     *        6X,22(1H*),/,16X,9HCOMPONENT,6X,3HASH,7X,9HCOMPONENT,4X,
     *        8HSOFTENER,11X,4HPOND,6X,8HSOFTENER,/,18X,5H(WT%),7X,
     *        5HINPUT,8X,5H(WT%),6X,9HCHEMICALS,9X,6HSLUDGE,6X,6HSLUDGE,
     *        /)
      DO 310 I=1,6
      WRITE(6,305) KLG(I),PNT(1,I),KLG(I+15),KLG(I+28),(PNT(J,I),J=2,4)
  305 FORMAT(16X,A6,8X,F5.2,5X,A6,A6,5X,F5.2,11X,F5.2,7X,F5.2)
  310 CONTINUE
      DO 320 I=7,11
      WRITE(6,305) KLG(I+1),PNT(1,I),KLG(I+15),KLG(I+28),(PNT(J,I),
     *              J=2,4)
  320 CONTINUE
      WRITE(6,330) KLG(13),KLG(42),PNT(1,12),KLG(27),KLG(40),(PNT(J,12),
     *              J=2,4)
  330 FORMAT(16X,A6,A6,F7.0,5X,A6,A6,5X,F5.2,11X,F5.2,7X,F5.2)
      WRITE(6,340) KLG(12),(PNT(J,13),J=2,4)
  340 FORMAT(40X,A6,10X,F6.2,10X,F6.2,6X,F6.2)
      WRITE(6,350) KLG(13),KLG(42),(PNT(J,14),J=2,4)
  350 FORMAT(40X,A6,A6,1X,F9.2,8X,F8.0,4X,F8.1,/)
C
C
C
      IF(ISOFT.EQ.0) GO TO 400
      SSRATE=SV(13,41)/DL(SV(13,5))/3785.43*60.0
      CAIN=SV(13,20)*XMW(83)/XSE009(13,3)*1000000.0
      CAOUT=SV(15,20)*XMW(83)/XSE009(15,3)*1000000.0
      WRITE(6,375) SSRATE,CAIN,CAOUT
  375 FORMAT(16X,23HSOFTENER OPERATING DATA,//,19X,17HTREATMENT RATE = ,
     *        F8.1,4H GPM,/,19X,26HINLET CA CONCENTRATION  = ,F8.2,
     *        4H PPM,/,19X,26HOUTLET CA CONCENTRATION = ,F8.2,4H PPM)
  400 CONTINUE
      OPN=4
```

```
        DO 410 I=2,9
        CALL XSE008(I,OPN)
    410 CONTINUE
        RETURN
        END

@PRT,S     X.XSE003/
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```
      COMPILER (STD=66)
      SUBROUTINE XSEU03(IATOM, IVCTOR)
      COMMON/BOX/DELTA(12)
C
C
C
      DOUBLE PRECISION LABEL,IDEQP
      COMMON/CMMN/SV(25,130),IDEQP(20),ISTM(25,10),ISEQ(25),PA(20,24),
     *             L(2),NL,LSRL(2),LERL(2),WV,DNAT(4),XA(4),LABEL(13),
     *             AH20
      DIMENSION G1(13),G2(13),G3(13),G4(13)
      DOUBLE PRECISION KELEM(13)
      DATA KELEM/5HH    ,5HC    ,5HN    ,5HO    ,5HNA   ,5HMG   ,
     *           5HS    ,5HCL   ,5HCA   ,5HINERT,5HP    ,5HSI   ,
     *           5HK    /
C
C
C
C
C
C
      LOC = ISEQ(NL)
C
C
C
      MASBAL = 1
      DO 10 I=1,13
      G1(I)=0.
      G2(I)=0.
      G3(I)=0.
      G4(I)=0.
   10 CONTINUE
C
      DO 50 J=1,5
      K=ISTM(LOC,J)
      IF (K .EQ. 0) GO TO 30
      K1=3
      CALL XSEU05(K,G3,K1)
C
C
C
      DO 20 I=1,13
   20 G1(I) = G1(I) + G3(I)
   30 K = ISTM(LOC,J+5)
      IF (K .EQ. 0) GO TO 50
      CALL XSE005(K,G4,K1)
C
C
C
      DO 40 I=1,13
   40 G2(I) = G2(I) + G4(I)
   50 CONTINUE
C
C
C
      DO 60 I=1,13
      G3(I) = G2(I) - G1(I)
      IF(ABS(G1(I)).LT. .001 .AND.ABS(G2(I)).LT. .001) GO TO 55
      G4(I) = G3(I)/(G2(I) + G1(I)) * 200.
      GO TO 56
   55 G4(I) = .0
   56 CONTINUE
C
      IF(ABS(G4(I)).LT.1.0) GO TO 60
      MASBAL = 0
   60 CONTINUE
C
      IF(MASBAL.EQ.1) RETURN
      IF(LOC.EQ.7.AND.MASBAL.EQ.0) SV(1,4)=1.0
      IF (MASBAL .EQ. 0) PRINT 110, IDEQP(LOC), LOC
  110 FORMAT(1H1,42HXSE003 PRINTOUT+  THE MASS BALANCE AROUND ,A6,
     * 18H, EQUIPMENT NUMBER,I3,19H, IS NOT SATISFIED.,/)
C
C
C
      PRINT 120
  120 FORMAT(1H+,40X,30HUNITS OF GRAM-ATOMS PER SECOND,/,/,7H TOTALS)
      PRINT 130
  130 FORMAT(1H+,7X,7HELEMENT,8X,5HINPUT,10X,6HOUTPUT,9X,5HDELTA,10X,
     *       7H% ERROR)
      DO 135 I=1,13
  135 PRINT 140,KELEM(I),G1(I),G2(I),G3(I),G4(I)
  140 FORMAT(10X,A5,4(5X,E10.4))
C
      DELTA(1)=G4(9)
      DELTA(2)=G4(6)
      DELTA(3)=G4(5)
      DELTA(4)=0.0
      DELTA(5)=G4(13)
      DELTA(6)=G4(8)
      DELTA(7)=0.0
      DELTA(8)=G4(7)
      DELTA(9)=G4(12)
      DELTA(10)=G4(11)
      DELTA(12)=G4(10)
      IF (IATOM .EQ. 0) GO TO 300
      PRINT 200
  200 FORMAT(1H1,5X,14H INPUT STREAMS,/,/)
      DO 280 J=1,10
      K = ISTM(LOC,J)
      IF (K .EQ. 0) GO TO 280
      IF(J.NE.6) GO TO 250
 220  PRINT 230
  230 FORMAT(1H+,14HOUTPUT STREAMS,/,/)
  250 CONTINUE
      K1=3
      CALL XSE005 (K,G1,K1)
      K1=0
      CALL XSE005(K,G2,K1)
      K1=1
      CALL XSE005(K,G3,K1)
      K1=2
      CALL XSE005(K,G4,K1)
      PRINT 260, K
  260 FORMAT(1H+,6HSV NO.,I3)
      PRINT 265
  265 FORMAT(7X,7HELEMENT,8X,5HTOTAL,12X,3HGAS,10X,6HLIQUID,10X,5HSOLID)
      DO 270 I=1,13
  270 PRINT 140,KELEM(I),G1(I),G2(I),G3(I),G4(I)
      PRINT 275
  275 FORMAT(1H1)
 280  CONTINUE
C
 300  IF (IVCTOR .NE. 1) RETURN
      DO 310 J=1,10
      K = ISTM(LOC,J)
      IF (K .EQ. 0) GO TO 310
      CALL XSE006(K)
      310 CONTINUE
          RETURN
          END

@PRT,S    X.XSE004/
```

```
      COMPILER (STD=66)
      SUBROUTINE XSE004(IUNITS,IOUT)
      DIMENSION KMW(13),C(6,2),TOT(22),SUM(22),TOTS(22),DW(22)
     $ ,TWTS(22),STRHD(6)
      COMMON/DPRT/T(42,22),M
      COMMON/ADDIT/XACID,XCAU,RHOA,RHOC
C
C
C
      DOUBLE PRECISION LABEL,IDEQP
      COMMON/CMMN/SV(25,130),IDEQP(20),ISTM(25,10),ISEQ(25),PA(20,24),
     *               L(2),NL,LSRL(2),LERL(2),WV,DNAT(4),XA(4),LABEL(13),
     *               AH20
      COMMON/LCMN/XMW(100),DHF(100),ENTO(100),ACP(100),BCP(100),CCP(100)
     *              ,DCP(100),TMIN(100),TMAX(100),ZE(100),ALIT(100),
     *              BLIT(100),UCAP(100),SPGR(25)
      DATA STRHD/4HINPU,4HT   ,4HOUTP,4HUT  ,4HINTE,4HRNAL/
      DATA KMW/83,84,85,86,87,88,89,90,91,35,93,46,38/
      DATA C/1.8,14.7,7.9365,19.468,.01585,1.,1.,1.,3.6,44.556,.0036,1./
      DL(T) = .99995282+.46726616E-4*(T-273.16)
     *                  -.74105074E-5*(T-273.16)**2
     *                  +.41079583E-7*(T-273.16)**3
     *                  -.13370708E-9*(T-273.16)**4
      JF = 10
      IF(IOUT.NE.2) JF=20
      DO  10  I = 1,40
      DO  10  J = 1,JF
   10 T(I,J) = .0
      M=IUNITS
      DO  100 J = 1,JF
C
C
C
      IF(SV(J   ,5) .LT. .1) GO TO 100
      T(1,J) = (SV(J   ,5) - 273.16)*C(1,M)
      IF(M .EQ. 1) T(1,J) = T(1,J) + 32.
      T(2,J) = SV(J   ,6)*C(2,M)
      IF(SV(J   ,10) .LT. .1) GO TO 20
C
C
C
      T(3,J)=0.
      DO 11 I=1,4
      IF(SV(J,I+10).LE.0.0) GO TO 11
      T(3,J)=T(3,J)+SV(J,I+10)*XMW(I)
   11 CONTINUE
      T(3,J)=T(3,J)*C(3,M)
      DO  15  K = 1,4
      IF(SV(J,K+10).LE.0.0) GO TO 15
      T(K+3,J)=SV(J,K+10)/SV(J,10)*100.
   15 CONTINUE
      T(8,J)=SV(J,118)*XMW(38)/(SV(J,10)-SV(J,13))*C(4,M)
      T(8,J) = SV(J    ,105)*C(4,M)*XMW(38)/SV(J    ,5)
   20 IF(SV(J    ,41) .LT. .1) GO TO 28
C
C
C
      SUM(J) = .0
      DO  25  K = 42,88
   25 SUM(J) = SUM(J) + SV(J    ,K)*XMW(K+5)
      DW(J) = 1. + SUM(J)/1000.
      DW(J)=DW(J)*DL(SV(J,5))
      SUM(J)=SUM(J)*SV(J,41)/1000.+SV(J,41)
      T(9,J)=SUM(J)/DW(J)
C
C
C
C
   28 IF(XSE009(J,5).LT.1.E-10) GO TO 31
      TOTS(J)= .0
      TWTS(J) = .0
      DO  30  K = 1,13
      TWTS(J) = TWTS(J) + SV(J    ,K+105)*XMW(K+25)
   30 TOTS(J) = TOTS(J) + SV(J    ,K+105)*XMW(K+25)/SPGR(K)
   31 T(9,J) = T(9,J)*C(5,M)
      IF(SV(J    ,41) .LT. 1.E-10) GO TO 48
      TOT(J) = .0
      KCALC=1
      CALL XSE008(J,KCALC)
      DO  35  K = 1,13
      KK = KMW(K)
   35 TOT(J) = TOT(J) + SV(J    ,K+19)*XMW(KK)
      T(22,J)=0.0
      DO 40 K=1,11
      KK = KMW(K)
```

```
          T(K+10,J)=SV(J,K+19)*XMW(KK)/TOT(J)*1000000.
       40 T(22,J)=T(22,J)+T(K+10,J)
C
C
C
C
C
C
C
          T(10,J)=TOT(J)*C(3,M)
          T(23,J)=0.
          DO 42 K=1,13
          T(23,J)=T(23,J)+SV(J,K+105)*XMW(K+25)
       42 CONTINUE
          T(23,J)=(T(23,J)*100.0)/(T(23,J)+T(10,J)/C(3,M))
C
C
          T(24,J)=SV(J,40)
          DO  45  K = 1,3
       45 T(K+24,J)=SV(J,99+K)
          T(28,J)=SV(J,39)
       48 IF(XSEU09(J,5).LT.1.E-10) GO TO 100
          T(29,J)=TWTS(J)*C(3,M)
C
C
C
          DO  50  K = 1,13
       50 T(29+K,J)=SV(J,K+105)*XMW(K+25)/TWTS(J)*100.
      100 CONTINUE
          IF(SV(3,28).GT.0.0) GO TO 90
          IF(SV(3,22).LE.0.0) GO TO 95
C
C
C
          T(9,3)=SV(3,41)/(1.0-XCAU)/RHOC*60.0*0.0002642
          IF(M.EQ.2) T(9,3)=T(9,3)*60.0*0.003785
          T(10,3)=SV(3,41)/(1.0-XCAU)*C(3,M)
          T(13,3)=SV(3,22)/SV(3,41)*XMW(85)*1000000.0
          T(16,3)=SV(3,25)/SV(3,41)*XMW(88)*1000000.0
          GO TO 95
       90 CONTINUE
C
C
```

```
C
      T(9,3)=SV(3,41)/(1.-XACID)/RHOA*60.*.0002642
      IF(M.EQ.2) T(9,3)=T(9,3)*60.*.003785
      T(10,3)=SV(3,41)/(1.-XACID)*C(3,M)
      T(19,3)=96./98.*XACID*1000000.
   95 CONTINUE
      PRINT 101,STRHD(1),STRHD(2)
      CALL XSE007(1,5)
      PRINT 101,STRHD(3),STRHD(4)
      CALL XSE007(6,10)
C
      PRINT 101,STRHD(5),STRHD(6)
      CALL XSE007(11,16)
      PRINT 101,STRHD(5),STRHD(6)
      CALL XSE007(17,22)
  101 FORMAT(1H1,26X,40HDETAILED RECIRCULATING ASH SLUICE WATER ,
     *          2A4,8H STREAMS)
      RETURN
      END

@PRT,S     X.XSE005/
```

```
                                                                 DATE 113084
390-1514*ASH(1).XSE005(41)
      COMPILER (STD=66)
      SUBROUTINE XSE005(K,G,J)
C
C
C
C
C
C
      DOUBLE PRECISION LABEL,IDEQP
      COMMON/CMMN/SV(25,130),IDEQP(20),ISTM(25,10),ISEQ(25),PA(20,24),
     *           L(2),NL,LSRL(2),LERL(2),WV,DNAT(4),XA(4),LABEL(13),
     *           AH20
      DIMENSION G(13)
C
C
C
C
      IF(J.EQ.0) GO TO 29
      IF(K.EQ.1) GO TO 15
      CALL XSE008(K,J)
   15 CONTINUE
      IRETRN=1
      IF(J.EQ.3) IRETRN=0
      DO 20 I=1,13
   20 G(I) = 0.
      G(1) = SV(K,23)*3. + SV(K,25) + SV(K,31)*2.
      G(2) = SV(K,26)
      G(3) = SV(K,27) + SV(K,23)
      G(4) = SV(K,20) + SV(K,21) + .5*(SV(K,22)+SV(K,24)) + 2.*(SV(K,26)
     *      +SV(K,29)) + 5./2.*(SV(K,27)+SV(K,30))+ 3.*SV(K,28)+SV(K,31)
      G(5) = SV(K,22)
      G(6) = SV(K,21)
      G(7) = SV(K,28)
      G(8) = SV(K,25)
      G(9) = SV(K,20)
      G(10) = SV(K,32)
      G(11) = SV(K,30)
      G(12) = SV(K,29)
      G(13) = SV(K,24)
      IF(K.EQ.1) GO TO 24
      K1=4
      CALL XSE008(K,K1)
      GO TO 28
   24 CONTINUE
      JJ=J+1
      GO TO (29,25,26,40),JJ
   25 CONTINUE
      IF(J.EQ.2) GO TO 26
      G(10)=0.0
      GO TO 28
   26 CONTINUE
      G10=G(10)
      DO 27 I=1,13
      G(I)=0.0
   27 CONTINUE
      G(10)=G10
   28 CONTINUE
C
C
C
      IF(IRETRN.EQ.1) RETURN
      GO TO 40
C
C
C
   29 CONTINUE
      DO 30 I=1,13
      G(I) = 0.
   30 CONTINUE
   40 G(1) = G(1) + SV(K,13)*2.
      G(2) = G(2) + SV(K,14)
      G(3) = G(3) + 2.*SV(K,11)
      G(4) = G(4) + 2.*SV(K,12) + SV(K,13) + 2.*SV(K,14)
      RETURN
      END

@PRT,S     X.XSE006/
```

```
      COMPILER (STD=66)
      SUBROUTINE XSE006(NS)
C
C
C
C
C
C
C
C
      DOUBLE PRECISION LABEL,IDEQP
      COMMON/CMMN/SV(25,130),IDEQP(20),ISTM(25,10),ISEQ(25),PA(20,24),
     *          L(2),NL,LSRL(2),LERL(2),WV,DNAT(4),XA(4),LABEL(13),
     *          AH20
      DOUBLE PRECISION ITEM(2,130),IUNIT(2,130),ITEM1(2,31)
      EQUIVALENCE(ITEM(1,100),ITEM1(1,1))
      DATA ITEM/8*5H     ,5HTEMPE,5HRATUR,5HPRESS,5HURE  ,5HENTHA,5HLPY
     * ,4*5H     ,5HGAS F,5HLOW  ,5HNITRO,5HGEN  ,5HOXYGE,5HN    ,5HWATE
     *R,5H    ,5HCO2  ,9*5H     ,5HP(CO2,5H)    ,5HTOT  ,5HCA   ,5HTOT
     * ,5HMG   ,5HTOT  ,5HNA   ,5HTOT  ,5HNH3  ,5HTOT  ,5HK    ,5HTOT  ,
     *5HCL   ,5HTOT  ,5HCO2  ,5HTOT  ,5HNO3  ,5HTOT  ,5HSO4  ,5HTOT  ,5H
     *SIO2 ,5HTOT  ,5HPO4  ,5HTOT  ,5HH2O  ,5HTOT  ,5HINERT,10*5H    ,5
     *HTDS(W,5HT)  ,5HION  ,5HSTNGH,5HPH   ,5H     ,5HLIQ H,5H2O   ,5HH
     *+   ,5H    ,5HOH-  ,5H     ,5HH2CO3,5H(L)  ,5HHCO3-,5H     ,5HHNO
     *3-,5H    ,5HH2SIO,5H4=   ,5HHSO4-,5H     ,5HH3SIO,5H4-   ,5HCAOH+
     *,5H    ,5HCAHCO,5H3+   ,5HCACO3,5H(L)  ,5HCANO3,5H+    ,5HCASO4,5
     *H(L)  ,5HMGOH+,5H      ,5HMGHCO,5H3+   ,5HMGCO3,5H(L)  ,5HMGSO4,5H(
     *L)  ,5HNAOH(,5HL)   ,5HNAHCO,5H3(L) ,5HNACO3,5H-    ,5HNANO3,5H(L)
     *  ,5HNASO4,5H-    ,5HNH3(L,5H)     ,5HNH4SO,5H4-   ,5HNH4HS,5HO4(L)
     *,5HNH4CO,5H3-   ,5HNH4HC,5HO3(L),5HH3PO4,5H(L)  ,5HH2PO4,5H-    ,5
     *HHPO4=,5H      ,5HCAH2P,5HO4+  ,5HCAHPO,5H4(L) ,5HCAPO4,5H-    ,5HM
     *GHPO,5H4(L) ,5HNH2CO,5HO-    ,5HKSO4-,5H      ,5HCA++ ,5H     ,5HMG+
     *+ ,5H     ,5HNA+  ,5H      ,5HNH4+ ,5H       ,5HK+   ,5H     ,5HCL-
     *,5H     ,5HCO3= ,5H      ,5HNO3- ,5H       ,5HSO4= ,5H      ,5HH4SIO,5
     *H4(L) ,5HPO4=-,5H     ,22*5H     /
      DATA ITEM1/5HRS(GY,5HPSUM),5HRS(CA,5HCO3) ,5HRS(MG,5HOH2) ,4*5H
     *  ,5HSUS S,5HOLIDS,5HCA(OH,5H)2    ,5HCACO3,5H      ,5HCA3(P,5HO4)2
     *,5HCASO4,5H(ANH),5HCASO4,5H.2H2O,5HMG(OH,5H)2    ,5HMGCO3,5H.5H2O,5
     *HSEPIO,5HLITE ,5HCAH2S,5HIO4   ,5HSIO2 ,5H      ,5HCAHPO,5H4     ,5HN
     *A2CO,5H3     ,5HINERT,5HS     ,24*5H     /
      DATA IUNIT/8*5H     ,5HDEG K,5HELVIN,5HATMOS,5HPHERE,5HCAL/S,5HEC
     *  ,4*5H      ,5HGMOLE,5H/SEC ,54*5H      ,5HWT. P,5HPM    ,4*5H     ,
      *5HG.H20,5H/SEC ,16*5H     ,5HMOLAL,5HITY  ,108*5H     ,5HWT. F,5HR
      *ACT.,50*5H    /
 1000 FORMAT(2X,48HVECTOR NO.   ITEM        QUANTITY         UNITS    , 2X,
     *             48HVECTOR NO.   ITEM        QUANTITY         UNITS    )
 1100 FORMAT(40X,21HSTREAM VECTOR LISTING,/,40X,14H    STREAM NO.,I3,/)
 1200 FORMAT(2X,I6,4X,2A5,E14.8,4X,2A5,2X,I6,4X,2A5,E14.8,4X,2A5)
 1300 FORMAT(1H1)
      IF(NS.EQ.0) RETURN
      PRINT 1300
      PRINT 1100,NS
      PRINT 1000
      I=5
      J=6
      PRINT 1200,I,ITEM(1,5),ITEM(2,5),SV(NS,I),IUNIT(1,5),IUNIT(2,5),
     *             J,ITEM(1,6),ITEM(2,6),SV(NS,J),IUNIT(1,6),IUNIT(2,6)
      I=7
      J=10
      PRINT 1200,I,ITEM(1,7),ITEM(2,7),SV(NS,I),IUNIT(1,7),IUNIT(2,7),
     *             J,ITEM(1,10),ITEM(2,10),SV(NS,J),IUNIT(1,10),IUNIT(2,
     *             10)
      DO 5 I=11,13,2
      J=I+1
    5 PRINT 1200,I,ITEM(1,I),ITEM(2,I),SV(NS,I),IUNIT(1,10),IUNIT(2,10),
     *             J,ITEM(1,J),ITEM(2,J),SV(NS,J),IUNIT(1,10),IUNIT(2,10)
      I = 19
      J = 20
      PRINT 1200,I,ITEM(1,I),ITEM(2,I),SV(NS,I),IUNIT(1,6),IUNIT(2,6),
     *             J,ITEM(1,J),ITEM(2,J),SV(NS,J),IUNIT(1,10),IUNIT(2,10)
      DO 10 I=21,31,2
      J=I+1
   10 PRINT 1200,I,ITEM(1,I),ITEM(2,I),SV(NS,I),IUNIT(1,10),IUNIT(2,10),
     *             J,ITEM(1,J),ITEM(2,J),SV(NS,J),IUNIT(1,10),IUNIT(2,10)
      I=38
      J=39
      PRINT 1200,I,ITEM(1,I),ITEM(2,I),SV(NS,I),IUNIT(1,I),IUNIT(2,I),
     *             J,ITEM(1,J),ITEM(2,J),SV(NS,J),IUNIT(1,1),IUNIT(2,1)
      I=40
      J=41
      PRINT 1200,I,ITEM(1,I),ITEM(2,I),SV(NS,I),IUNIT(1,1),IUNIT(2,1),
     *             J,ITEM(1,J),ITEM(2,J),SV(NS,J),IUNIT(1,J),IUNIT(2,J)
      DO 15 I=42,86,2
      J=I+1
   15 PRINT 1200,I,ITEM(1,I),ITEM(2,I),SV(NS,I),IUNIT(1,50),IUNIT(2,50),
     *             J,ITEM(1,J),ITEM(2,J),SV(NS,J),IUNIT(1,50),IUNIT(2,50)
      I=88
      J=100
      PRINT 1200,I,ITEM(1,I),ITEM(2,I),SV(NS,I),IUNIT(1,50),IUNIT(2,50),
     *             J,ITEM(1,J),ITEM(2,J),SV(NS,J),IUNIT(1,1),IUNIT(2,1)
      I=101
      J=102
      PRINT 1200,I,ITEM(1,I),ITEM(2,I),SV(NS,I),IUNIT(1,1),IUNIT(2,1),
     *             J,ITEM(1,J),ITEM(2,J),SV(NS,J),IUNIT(1,1),IUNIT(2,1)
      I = 105
      J = 106
      PRINT 1200,I,ITEM(1,I),ITEM(2,I),SV(NS,I),IUNIT(1,I),IUNIT(2,I),
     *            J,ITEM(1,J),ITEM(2,J),SV(NS,J),IUNIT(1,10),IUNIT(2,10)
      DO 20 I=107,117,2
      J=I+1
   20 PRINT 1200,I,ITEM(1,I),ITEM(2,I),SV(NS,I),IUNIT(1,10),IUNIT(2,10),
     *             J,ITEM(1,J),ITEM(2,J),SV(NS,J),IUNIT(1,10),IUNIT(2,10)
      RETURN
      END

@PRT,S     X.XSE007/
```

```
390-1514*ASH(1).XSE007(45)
      COMPILER (STD=66)
      SUBROUTINE XSE007(JBEG,JEND)
      DOUBLE PRECISION STRID(84),UNITS(42,2)
      DIMENSION JCOL(22)
      COMMON/DPRT/T(42,22),M
      DATA JCOL/1,2,3,4,5,6,7,8,9,10,11,12,13,14,15,16,17,18,19,20,21,
     $ 22/
      DATA STRID/6HTEMPER,6HATURE,,6HPRESSU,6HRE,   ,6HTOT GA,6HS FLOW,
     *6HMOLE %,6H  N2  ,6H      ,6H  O2  ,6H      ,6H  H2O ,6H      ,
     *6H  CO2 ,6H DUST,,6H DRY  ,6HTOTAL ,6HLIQUID,6H      ,6H      ,
     *6H   CA ,6H      ,
     *6H   MG ,6H      ,6H   NA ,6H      ,6H   NH4,6H      ,6H   K  ,
     *6H      ,6H   CL ,6H      ,6H   CO3,6H      ,6H   NO3,6H      ,
     *6H   SO4,6H      ,6H   SIO,6H2     ,6H   PO4,6H      ,6H   TDS,
     *6H      ,6HSUS SO,6HL WT %,6HPH    ,6H      ,6HR.S. G,6HYPSUM ,
     *6H     C,6HACO3  ,6H     M,6HG(OH)2,6HIONIC ,6HSTR.  ,6HTOT SO,
     *6HLIDS  ,6H  CA(O,6HH)2    ,
     $ 6H  CACO,6H3     ,6H  CA3(,6HPO4)2 ,6H  CASO,6H4,ANH ,6H  CASO,
     $ 6H4,GYP ,6H  MG(O,6HH)2    ,6H  MGCO,6H3.5H2O,6H  SEPI,6HOLITE ,
     $ 6H  CAH2,6HSIO4  ,6H  SIO2,6H      ,6H  CAHP,6HO4    ,6H  NA2C,
     $6HO3    ,
     $ 6H  INER,6HT     /
      DATA UNITS/6HDEG F ,6HPSIA  ,6HLB/HR ,6H      ,6H      ,6H      ,
     * 6H      ,6HGR/SCF,6H GPM  ,6H LB/HR,6HPPM   ,6H      ,6H      ,
     * 6H      ,6H      ,6H      ,6H      ,6H      ,6H      ,6H      ,
     * 6H      ,6H      ,6H      ,6H      ,6H      ,6H      ,6H      ,
     * 6H      ,6H LB/HR,6HWT. % ,6H      ,6H      ,6H      ,6H      ,
     * 6H      ,6H      ,6H      ,6H      ,6H      ,6H      ,6H      ,
     * 6H      ,6HDEG C ,6HATM.  ,6H KG/HR,6H      ,6H      ,6H      ,
     * 6H      ,6HGM/M3 ,6HM3/HR ,6H KG/HR,6HPPM   ,6H      ,6H      ,
     * 6H      ,6H      ,6H      ,6H      ,6H      ,6H      ,6H      ,
     * 6H      ,6H      ,6H      ,6H      ,6H      ,6H      ,6H      ,
     * 6H      ,6H KG/HR,6HWT. % ,6H      ,6H      ,6H      ,6H      ,
     * 6H      ,6H      ,6H      ,6H      ,6H      ,6H      ,6H      ,
     * 6H      /
      PRINT 100
      PRINT 101, (JCOL(J), J = JBEG,JEND)
      PRINT 104
      DO 21 I=1,42
      IF(I.EQ.3.OR.I.EQ.9.OR.I.EQ.29) WRITE(6,103)
      PRINT 102, STRID(2*I-1),STRID(2*I),UNITS(I,M)
C
```

```
C
C
      DO  20  J = JBEG,JEND
      IF(T(I,J) .LT. 1.E-10) GO TO 20
      JGO = J - JBEG + 1
      GO TO(1,2,3,4,5,6), JGO
    1 PRINT 11, T(I,J)
      GO TO 20
    2 PRINT 12, T(I,J)
      GO TO 20
    3 PRINT 13, T(I,J)
      GO TO 20
    4 PRINT 14, T(I,J)
      GO TO 20
    5 PRINT 15, T(I,J)
      GO TO 20
    6 PRINT 16, T(I,J)
   20 CONTINUE
   21 CONTINUE
  100 FORMAT(
     $16HOSTREAM ID,UNITS,T55,14HSTREAM  NUMBER/T28,82H-----------------
     $-----------------------------------------------------------------)
  101 FORMAT(1H ,T17,6I15)
  102 FORMAT(1H ,2A6,2X,A6)
  103 FORMAT(1H )
  104 FORMAT(T27,83H ---------------------------------------------------
     $-------------------------------)
   11 FORMAT(1H+,T20,E15.4)
   12 FORMAT(1H+,T35,E15.4)
   13 FORMAT(1H+,T50,E15.4)
   14 FORMAT(1H+,T65,E15.4)
   15 FORMAT(1H+,T80,E15.4)
   16 FORMAT(1H+,T95,E15.4)
      RETURN
      END

@PRT,S     X.XSE008/
```

```
390-1514*ASH(1).XSE008(40)
      COMPILER (STD=66)
      SUBROUTINE XSE008(LSV,OPN)
C
C
C
C
C
C
C
C
C
C
C
C
C
      DOUBLE PRECISION LABEL,IDEQP
      COMMON/CMMN/SV(25,130),IDEQP(20),ISTM(25,10),ISEQ(25),PA(20,24),
     *             L(2),NL,LSRL(2),LERL(2),WV,DNAT(4),XA(4),LABEL(13),
     *             AH20
      DIMENSION X(130)
      INTEGER OPN
      DO 5 I=20,130
    5 X(I) = SV(LSV,I)
      GO TO (6,25,8,8),OPN
C
C
C
    6 CONTINUE
      LIQUID = 1
      GO TO 10
C
C
C
    8 CONTINUE
      LIQUID = 0
C
C
C
   10 X(20) = X(50)+X(51)+X(52)+X(53)+X(54)+X(72)+X(73)+X(74)+X(78)
      X(21) = X(55)+X(56)+X(57)+X(58)+X(75)+X(79)
      X(22) = X(59)+X(60)+X(61)+X(62)+X(63)+X(80)
      X(23) = X(64)+X(65)+X(66)+X(67)+X(68)+X(76)+X(81)
      X(24) = X(77)+X(82)
      X(25) = X(83)
      X(26) = X(44)+X(45)+X(51)+X(52)+X(56)+X(57)+X(60)+X(61)+X(67)+
     * X(68)+X(76)+X(84)
      X(27) = X(46)+X(53)+X(62)+X(85)
      X(28) = X(48)+X(54)+X(58)+X(63)+X(65)+X(66)+X(77)+X(86)
      X(29) = X(47)+X(49)+X(87)
      X(30) = X(69)+X(70)+X(71)+X(72)+X(73)+X(74)+X(75)+X(88)
      X(31) = 0.5*X(42)+X(44)+.5*X(45)+.5*X(46)+.5*
     *     X(48)+.5*(X(50)+X(51)+X(55)+X(56)+X(59)+X(60)+
     *       X(66)+X(68))+1.5*X(69)+X(70)+0.5*X(71)+X(72)+0.5*X(73)+
     *     0.5*X(75)-.5*X(83)-2.*X(87)-X(47)-1.5*X(49)
      X(32) = 0.
C
C
C
      DO 20 I = 20, 31
   20 X(I) = X(I) * X(41)/1000.
      X(31)=X(31)+X(41)/18.016
C
C
C
      IF(LIQUID.EQ.1) GO TO 38
      GO TO 35
C
C
C
   25 CONTINUE
      DO 30 I=20,32
      X(I) = 0.
   30 CONTINUE
   35 CONTINUE
      X(20) = X(20)+X(106)+X(107)+X(108)+X(109)+X(110)+X(116)+X(114)
      X(21) = X(21)+X(111)+X(112)+2.*X(113)
      X(27) = X(27)
      X(26) = X(26)+X(107)+X(112) +X(117)
      X(25) = X(25)
      X(24) = X(24)
      X(23) = X(23)
      X(22) = X(22)+2.*X(117)
      X(28) = X(28)+X(109)+X(110)
      X(29) = X(29)+3.*X(113)+1.*X(114)+X(115)
      X(30) = X(30)+2.*X(108)+X(116)
      X(31) = X(31)+X(106)+2.*X(110)+X(111)+5.*X(112)+2.*X(113)+1.*
     * X(114)+0.5*X(116)
      X(32) = X(32)+X(118)
      IF(OPN.EQ.4) X(31)=X(31)+SV(LSV,13)
   38 CONTINUE
      DO 40 I=20,32
      SV(LSV,I) = X(I)
   40 CONTINUE
      RETURN
      END

@PRT,S    X.XSEOU9/
```

```
                                                                           DATE 113084
390-1514*ASH(1).XSED09(40)
          COMPILER (STD=66)
          REAL FUNCTION XSED09(K,I)
C
C
C
C
C
C
C
C
      DOUBLE PRECISION LABEL,IDEQP
      COMMON/CMMN/SV(25,130),IDEQP(20),ISTM(25,10),ISEQ(25),PA(20,24),
     *             L(2),NL,LSRL(2),LERL(2),WV,DNAT(4),XA(4),LABEL(13),
     *             AH2O
      COMMON/LCMN/XMW(100),DHF(100),ENTO(100),ACP(100),BCP(100),CCP(100)
     *             ,DCP(100),TMIN(100),TMAX(100),ZE(100),ALIT(100),
     *             BLIT(100),UCAP(100),SPGR(25)
C
C
C
      WGAS=0.
      DO 10 J=1,4
   10 WGAS=WGAS+SV(K,J+10)*XMW(J)
C
C
C
      WLIQ = SV(K,41)
      DO 15 J=1,47
   15 WLIQ = WLIQ + SV(K,J+41)*XMW(J+46)*SV(K,41)/1000.
C
C
C
      WSOLID=0.
      DO 20 J=1,13
   20 WSOLID = WSOLID + SV(K,J+105)*XMW(J+25)
C
C
C
      WNESLD = SV(K,117)*XMW(37)+SV(K,118)*XMW(38)
      XSED09=0.
      IF(I.LE.2)  XSED09 = WGAS
      IF(I.LE.4.AND.I.NE.2) XSED09=XSED09 + WLIQ
      IF(I.GE.4.AND.I.NE.7.OR.I.EQ.1) XSE009 =XSE009 + WSOLID
      IF(I .GE.6) XSE009=XSE009+(2.*FLOAT(I)-13.)*WNESLD
      RETURN
      END

@PRT,S     X.YEQ001/
```

```
390-1514*ASH(1).YEQ001(43)                                                          DATE 113084
      COMPILER (STD=66)
      SUBROUTINE YEQ001(LSV,IOP,T,PP,   WNES,NS)
C
C
C
C

      DIMENSION X(100),Y(30),C(10),A(10),PP(4)
      DIMENSION IOP(35)
      DIMENSION KK(13)
C
C
C

      DOUBLE PRECISION LABEL,IDEQP
      COMMON/CMMN/SV(25,130),IDEQP(20),ISTM(25,10),ISEQ(25),PA(20,24),
     *          L(2),NL,LSRL(2),LERL(2),WV,DNAT(4),XA(4),LABEL(13),
     *          AH20
      COMMON/LCMN/XMW(100),DHF(100),ENTO(100),ACP(100),BCP(100),CCP(100)
     *          ,DCP(100),TMIN(100),TMAX(100),ZE(100),ALIT(100),
     *          BLIT(100),UCAP(100),SPGR(25)
      COMMON/GAM/ GLN(30),GLND(100),GW,FI
     $ ,GAMLN(130),DGAMLN(130)
      COMMON/SOLIDS/ LOCSDS,CKS(30),XHY(30),ESK(30,30),ISK(30),APS(30)
      COMMON/GAMD/ DGLN(30),DGLND(100),IZI(30),IZD(100)
      COMMON/COUNTS/NAVCAT,NAVAN,NAVSOL,NCAT,NAN,NAVSPE
      COMMON/EQVAL/TH1,TH2,BETA,ETA(100,30),TH(30)
      COMMON/TRFR/XXMW
      COMMON/RATE/ XNI(30),BB(30),RK(30),RM(30),VRK(30)
      COMMON/FLAG/ IFLAG
      COMMON/PPT/ IRATE
      DATA KK/83,84,85,86,87,88,89,90,91,35,93,46,38/
        DL(X) = .99995282 + .46726616E-4*(X-273.16)
     $   - .74105074E-5 * (X-273.16)**2
     $   + .41079583E-7 * (X-273.16)**3
     $   - .13370708E-9 * (X-273.16)**4
      IF(IRATE .NE. 0) GO TO 51
      DO  50  I = 1,NAVSOL
      VRK(I) = .0
   50 CONTINUE
   51 CONTINUE
      DO  77  I = 1,NAVSOL
      IF(VRK(I) .NE. .0) IOP(I+20) =1
   77 CONTINUE
```

```
      C(1) = SV(LSV,31)
      DO  1  I = 2,NAVCAT
      J = 18 + I
      C(I) = SV(LSV,J)
    1 CONTINUE
      DO  2  I = 1,NAVAN
    2 A(I) = SV(LSV,I+24)
      NTOT = NAVCAT + NAVAN
      Y(1) = SV(LSV,42)
      DO  3  I = 2,NTOT
    3 Y(I)=0.0
      XCON = SV(LSV,41)/1000.
      XXMW = XCON
      IOP(20) = 1
      LSDS = 106 - LOCSDS
      NDSDS = LOCSDS + NAVSOL
      IF(NS .NE. 1) GO TO 60
      DO  55  I = LOCSDS,NDSDS
   55 Y(I) = .0
      GO TO 65
   60 DO  61  I = LOCSDS,NDSDS
   61 Y(I) = SV(LSV,I+LSDS)
   65 CALL YEQ002(PP,PH,T,IOP)
      DLT = DL(T)
      DO  74  I = 1,NAVSOL
   74 IF(IOP(I+20).NE.0) BB(I)= VRK(I)*DLT*XMW(25+I)*EXP(CKS(I))
      DO  70  I = 1,NAVSPE
   70 X(I)=0.0
      IF(NS.EQ.0) IOP(16)=0
      IF(NS .EQ. 1) IOP(16) = 1
      IF(IOP(1) .NE. 0) PH = SV(LSV,40)
      IF(IOP(17) .NE. 0) GO TO 88
      CALL YEQ003(Y,X,C,A,T,IOP,PP,PH)
      GO TO 84
   88 CONTINUE
      XS = SV(LSV,105)
      AA = XS*18.016
      PHIP = AA
      IF(C(1) .GT. .0) GO TO 86
      WES = C(2)*56. + A(2)*44.
      C(1) = WES/AA
   86 CALL YEQ003(Y,X,C,A,T,IOP,PP,PH)
      LMW = 26 - LOCSDS
      WES1 = .0
      DO  800 I = LOCSDS,NDSDS
  800 WES1 = WES1 + Y(I)*XMW(LMW+I)
      WES = WES1*XXMW
      B = WNES*(1. - XS)
      B1 = XS*(C(2)*56.08 + C(3)*40.32 + C(4)*31. + C(6)*35.5
     *  + A(2)*44. + A(5)*60. + A(6)*71. + A(4)*80.066)
      B = B1 - B
      PHI = AA*C(1) - WES + B
      CIP1 = C(1) - PHI/PHIP
      IF(CIP1 .LE. .0) CIP1 = C(1)*.8
      XSI = (B1 + AA*C(1))/XS
      XSI = (WES + WNES)/(XSI + WNES)
      TSTV = (ABS(XSI- XS))/XS
      IF(TSTV .LE. 1.E-3) GO TO 83
      C(1) = CIP1
      GO TO 86
   83 CONTINUE
      PXSI = XSI*100.
      IF(IFLAG .EQ.0) PRINT 1000, PXSI,WNES
 1000 FORMAT(15X,7HXS =    ,F7.4,T71,11HWNES    =    ,1PE10.3)
   84 CONTINUE
      SV(LSV,31) = C(1)
      XCON = XXMW
      AH2O = GW
      SV(LSV,39) = FI
      SV(LSV,41) = XCON*1000.
      SV(LSV,40) = PH
      DO  15  I = 2,NAVCAT
      J = 18 + I
      SV(LSV,J) = C(I)
   15 CONTINUE
      DO  20  I = 1,NAVAN
   20 SV(LSV,I+24) = A(I)
      DO  71  I = 1,30
   71 IF(Y(I).LE.1.E-15) Y(I)=.0
      SV(LSV,42) = Y(1)
      DO  90  I = 2,NTOT
   90 SV(LSV,I+76) = Y(I)
      DO  95  I = LOCSDS,NDSDS
   95 SV(LSV,I+LSDS)=Y(I)*XCON
      DO  100  I = 1,NAVSPE
  100 SV(LSV,I+42) = X(I)
```

```
      SV(LSV,100)=EXP(APS(5)-CKS(5))
      SV(LSV,101)=EXP(APS(2)-CKS(2))
      SV(LSV,102)=EXP(APS(6)-CKS(6))
      SV(LSV,38)=0.
      DO 110 I=20,32
      IF(I.EQ.31) GO TO 110
      KN=KK(I-19)
      SV(LSV,38)=SV(LSV,38)+SV(LSV,I)*XMW(KN)
  110 CONTINUE
      N=3
      SV(LSV,38)=SV(LSV,38)/XSE009(LSV,N)*1000000.
      SV(LSV,118)=SV(LSV,32)
      SV(LSV,105)=XSE009(LSV,5)/XSE009(LSV,1)
      RETURN
      END

@PRT,S     X.YEQ002/
```

```
      COMPILER (STD=66)
      SUBROUTINE YEQ002 (PP,PH,TK,IOPT)
      REAL            NHY
C
      REAL            K25L         ,K25S         ,K25P
C
      DOUBLE PRECISION LBL(500),LBS(200),LBP(50)
C
      COMMON /COUNTS/NAVCAT        ,NAVAN        ,NAVSOL       ,NCAT
     1 ,NAN           ,NAVSPE
C
      COMMON /FUNC  /F(30)         ,CK(100)      ,CT(30)       ,PCK(30)
C
      DIMENSION       PP(1)        ,IOPT(1)      ,IHY(2)
C
      COMMON/TEMPER/TC ,DUMMY
C
      COMMON /SOLIDS/LOCSDS        ,CKS(30)      ,NHY(30)      ,ESK(30,30)
     1 ,ISK(30)       ,APS(30)
C
      COMMON /ECONTS/A(100)        ,B(100)       ,C(100)       ,D(100)
     1 ,PA(10)        ,PB(10)      ,PC(10)       ,PPD(10)      ,SA(30)
     2 ,SB(30)        ,SC(30)      ,SD(30)       ,K25L(100)    ,K25S(30)
     3 ,K25P(10)
C
      COMMON/NUM/NUMIPR
      COMMON/FLAG/IFLAG
      DATA LBL(1),LBL(2),LBL(3),LBL(4),LBL(5),LBL(6),LBL(7),
     1 LBL(8),LBL(9),LBL(10),LBL(11),LBL(12),LBL(13),LBL(14),
     1 LBL(15),LBL(16)
     1/8HH2O = H+,8H + OH-  ,8H           ,8H       ,
     1 8HH2CO3 = ,8H2H+ + CO,8H3=         ,8H       ,
     1 8HHCO3- = ,8HH+ + CO3,8H=          ,8H       ,
     1 8HHNO3 = H,8H+ + NO3-,8H           ,8H       /
      DATA LBL(17),LBL(18),LBL(19),LBL(20),LBL(21),LBL(22),
     1 LBL(23),LBL(24),LBL(25),LBL(26),LBL(27),LBL(28),
     1 LBL(29),LBL(30),LBL(31),LBL(32)
     1/8HH2SIO4= ,8H= H4SIO4,8H -2H+     ,8H       ,
     1 8HHSO4- = ,8HH+ + SO4,8H=          ,8H       ,
     1 8HH3SIO4 =,8H H4SIO4 ,8H- H+       ,8H       ,
     1 8HCAOH+ = ,8HCA++ + H,8H2O - H+ ,8H          /
      DATA LBL(33),LBL(34),LBL(35),LBL(36),LBL(37),LBL(38),
      1 LBL(39),LBL(40),LBL(41),LBL(42),LBL(43),LBL(44),
      1 LBL(45),LBL(46),LBL(47),LBL(48)
      1/8HCAHCO3+ ,8H= CA++ +,8H H+ + CO,8H3=       ,
      1 8HCACO3 = ,8HCA++ + C,8HO3=      ,8H        ,
      1 8HCANO3+ =,8H CA++ + ,8HNO3-     ,8H        ,
      1 8HCASO4 = ,8HCA++ + S,8HO4=      ,8H        /
       DATA LBL(49),LBL(50),LBL(51),LBL(52),LBL(53),LBL(54),
      1 LBL(55),LBL(56),LBL(57),LBL(58),LBL(59),LBL(60),
      1 LBL(61),LBL(62),LBL(63),LBL(64)
      1/8HMGOH+ = ,8HMG++ + H,8H2O - H+ ,8H        ,
      1 8HMGHCO3+ ,8H= MG++ +,8H H+ + CO,8H3=       ,
      1 8HMGCO3 = ,8HMG++ + C,8HO3=      ,8H        ,
      1 8HMGSO4 = ,8HMG++ + S,8HO4=      ,8H        /
       DATA LBL(65),LBL(66),LBL(67),LBL(68),LBL(69),LBL(70),
      1 LBL(71),LBL(72),LBL(73),LBL(74),LBL(75),LBL(76),
      1 LBL(77),LBL(78),LBL(79),LBL(80)
      1/8HNAOH =  ,8HNA+ + H2,8HO - H+   ,8H        ,
      1 8HNAHCO3 =,8H NA+ + H,8H+ + CO3=,8H        ,
      1 8HNACO3- =,8H NA+ + C,8HO3=      ,8H        ,
      1 8HNANO3 = ,8HNA+ + NO,8H3-       ,8H        /
       DATA LBL(81),LBL(82),LBL(83),LBL(84),LBL(85),LBL(86),
      1 LBL(87),LBL(88),LBL(89),LBL(90),LBL(91),LBL(92),
      1 LBL(93),LBL(94),LBL(95),LBL(96)
      1/8HNASO4- =,8H NA+ + S,8HO4=      ,8H        ,
      1 8HNH3(L) =,8H NH4+ - ,8HH+       ,8H        ,
      1 8HNH4SO4- ,8H= NH4+ +,8H SO4=    ,8H        ,
      1 8HNH4HSO4 ,8H= NH4+ +,8H H+ + SO,8H4=       /
       DATA LBL(97),LBL(98),LBL(99),LBL(100),LBL(101),LBL(102),
      1 LBL(103),LBL(104),LBL(105),LBL(106),LBL(107),LBL(108),
      1 LBL(109),LBL(110),LBL(111),LBL(112)
      1/8HNH4CO3- ,8H= NH4+ +,8H CO3=    ,8H        ,
      1 8HNH4HCO3 ,8H= NH4+ +,8H H+ + CO,8H3=       ,
      1 8HH3PO4 = ,8HPO4--- +,8H 3H+    ,8H        ,
      1 8HH2PO4- =,8H PO4--- ,8H+ 2H+   ,8H        /
       DATA LBL(113),LBL(114),LBL(115),LBL(116),LBL(117),
      1 LBL(118),LBL(119),LBL(120),LBL(121),LBL(122),
      1 LBL(123),LBL(124),LBL(125),LBL(126),LBL(127),LBL(128)
      1/8HHPO4= = ,8HPO4--- +,8H H+      ,8H        ,
      1 8HCAH2PO4+,8H = CA++ ,8H+ 2H+ + ,8HPO4---   ,
      1 8HCAHPO4 =,8H CA++ + ,8HH+ + PO4,8H---       ,
      1 8HCAPO4- =,8H CA++ + ,8HPO4---  ,8H        /
       DATA LBL(129),LBL(130),LBL(131),LBL(132),LBL(133),
      1 LBL(134),LBL(135),LBL(136),LBL(137),LBL(138),
     1 LBL(139),LBL(140)
     1/8HMGPO4- =,8H MG++ + ,8HPO4---  ,8H        ,
     1 8HNH2COO- ,8H= NH4+ +,8HCO3=    ,8H        ,
     1 8HKSO4- = ,8HK+ + SO4,8H=       ,8H        /
      DATA LBS/8HCA(OH)2(,8HS) = CA+,8H+ + 2OH-,8H        ,
     1         8HCACO3(S),8H = CA++ ,8H+ CO3=  ,8H        ,
     1         8HCA3(PO4),8H2 = 3CA+,8H+ + 2PO4,8H---     ,
     1         8HCASO4(S,,8HANH) = C,8HA++ + SO,8H4=      ,
     1         8HCASO4(S),8H2H2O = C,8HA++ + SO,8H4=      ,
     1         8HMG(OH)2(,8HS) = MG+,8H+ + 2OH-,8H        ,
     1         8HMGCO3(8),8H5H2O = M,8HG++ + CO,8H3=      ,
     1         8HSEPIOLIT,8HE = 3H4S,8HIO4+2MG+,8H+ + 4OH-,
     1         8HCAH2SIO4,8H(S) = CA,8H++ +H4SI,8HO4 - 2H+,
     1         8HSIO2(S) ,8H+ 2H2O =,8HH4SIO4   ,8H        ,
     1         8HCAHPO4(S,8H) = CA++,8H + H+ + ,8HPO4---  /
      DATA LBP/8HCO2(G) +,8H H2O = H,8H2CO3    ,8H        ,
     1         8HHNO3(G) ,8H= HNO3(L,8H)       ,8H        ,
     1         8HNH3(G) =,8H NH3(L) ,8H        ,8H        /
      DATA IHY/2,0/
C
C
C
      IF (TOLD.EQ.TK) RETURN
      NUMIPR = 0
      TC=TK-273.16
      DM=2.3025851
      DO 10 I=1,NAVSPE
      XLK=-A(I)/TK-B(I)*ALOG10(TK)-C(I)*TK+D(I)
      CK(I)=XLK*DM
 10   CONTINUE
      DO  20  I = 1,3
      PCK(I)=DM*(-PA(I)/TK-PB(I)*ALOG10(TK)-PC(I)*TK+PPD(I))
 20   CONTINUE
C
C
C
      DO 30 I=1,NAVSOL
      CKS(I)=DM*(-SA(I)/TK-SB(I)*ALOG10(TK)-SC(I)*TK+SD(I))
 30   CONTINUE
C
C
      TOLD=TK
      IF(IFLAG .EQ. 0) WRITE(6,70) TC
      DO 40 I=1,NAVSPE
      IND=I*4-3
      ECK=EXP(CK(I))
      INDP3=IND+3
      IF(IFLAG .EQ. 0) WRITE(6,80) (LBL(J),J=IND,INDP3),K25L(I),ECK
   40 CONTINUE
      IF(IFLAG .EQ. 0) WRITE(6,90)
      DO 50 I=1,NAVSOL
      ECKS=EXP(CKS(I))
      IF (I.EQ.1.OR.I.EQ.6) ECKS=ECKS*EXP(2.*CK(1))
      IF (I.EQ.8) ECKS=ECKS*EXP(4.*CK(1))
      IND=I*4-3
      INDP3=IND+3
      IF(IFLAG .EQ. 0) WRITE(6,80) (LBS(J),J=IND,INDP3),K25S(I),ECKS
   50 CONTINUE
      CKS(9) = CKS(9)+CK(5)
      IF(IFLAG .EQ. 0) WRITE(6,90)
      DO 60 I=1,3
      EPCK=EXP(PCK(I))
      IND=I*4-3
      INDP3=IND+3
      IF(IFLAG .EQ. 0) WRITE(6,80) (LBP(J),J=IND,INDP3),K25P(I),EPCK
   60 CONTINUE
      IF(IFLAG .EQ. 0) WRITE(6,90)
      IH=IOPT(18)+1
      IF(IFLAG .EQ. 0) WRITE(6,100) IHY(IH)
      RETURN
C
   70 FORMAT (1H1,40X,11HTEMPERATURE,F8.3,8H  DEG. C,//45X,21HEQUILIBRIU
     1M CONSTANTS/33X,8HREACTION,17X,7HK(25 C),8X,7HK(TEMP)/)
   80 FORMAT (27X,4A8,2(1PE9.3,6X))
   90 FORMAT (1H )
  100 FORMAT (28X,35HHYDRATES IF PRECIPITATED ARE CASO4.,I1,15HH2O,MGCO3
     1.5H2O")
      END

@PRT,S     X.YEQ003/
```

```
      COMPILER (STD=66)
      SUBROUTINE YEQ003 (YYM,XXM,CAT,AN,TTK,IIOPT,PPP,PPH)
      REAL            MLCWTR
C
      REAL            NHY
C
      DIMENSION       YYM(1)       ,XXM(1)       ,CAT(1)       ,AN(1)
     1 ,PPP(1)
C
      DIMENSION       IIOPT(1)
C
      COMMON /COUNTS/NAVCAT        ,NAVAN        ,NAVSOL       ,NCAT
     1 ,NAN           ,NAVSPE
C
      COMMON /EQVAL /TH1           ,TH2          ,BETA         ,ETA(100,30)
     1 ,TH(30)
C
      COMMON /FUNC  /F(30)         ,CK(100)      ,CT(30)       ,PCK(30)
C
      COMMON /GAM   /GLN(30)       ,GLND(100)    ,GW           ,FI
     $ ,GAMLN(130),DGAMLN(130)
C
      COMMON /NAMES /NUMI          ,NUMD         ,ID(100)      ,IV(30)
     1 ,IPHI(30)      ,NEQ         ,NS           ,NEGL
C
      COMMON /OPTN  /PP(30)        ,PH           ,TK           ,IOPT(35)
C
      COMMON /VARBLE/YM(30)        ,XM(100)      ,Y(30)
C
      COMMON /SOLIDS/LOCSDS        ,CKS(30)      ,NHY(30)      ,ESK(30,30)
     1 ,ISK(30)       ,APS(30)
C
      COMMON /TRFR  /XMW
C
      INTEGER         SPECES(100) ,SOLIDS(30)   ,ANTAB(30)
C
      DOUBLE PRECISION LB(260)
C
      DIMENSION       ICAT(10)     ,IAN(10)
C
      COMMON /RESEN /REN
C
```

```
              COMMON /H2O   /CH
              COMMON/FLAG/IFLAG
        C
              COMMON /RATE  /XNI(30)      ,BB(30)      ,RK(30)      ,RM(30)
        C
              DIMENSION       IRT(30)
        C
              DATA IRT/73,75,77,117,79,81,83,85,87,89,115/
              DATA ANTAB/51,1,52,2,53,3,54,4,55,5,56,6,8*0/
              DATA LB/6HH+     ,6H          ,6HOH-    ,6H         ,6HH2CO3 ,6H        ,
             1        6HHCO3- ,6H          ,6HHNO3   ,6H         ,6HH2SIO4,6H=       ,
             2        6HHSO4- ,6H          ,6HH3SIO4,6H-         ,6HCAOH+ ,6H        ,
             3        6HCAHCO3,6H+         ,6HCACO3  ,6H         ,6HCANO3+,6H        ,
             4        6HCASO4 ,6H          ,6HMGOH+  ,6H         ,6HMGHCO3,6H+       ,
             5        6HMGCO3 ,6H          ,6HMGSO4  ,6H         ,6HNAOH  ,6H        ,
             6        6HNAHCO3,6H          ,6HNACO3-,6H          ,6HNANO3 ,6H        ,
             7        6HNASO4-,6H          ,6HNH3(L),6H          ,6HNH4SO4,6H-       ,
             8        6HNH4HSO,6H4         ,6HNH4CO3,6H-         ,6HNH4HCO,6H3       ,
             9        6HH3PO4 ,6H          ,6HH2PO4-,6H          ,6HHPO4= ,6H        ,
             A        6HCAH2PO,6H4+        ,6HCAHPO4,6H          ,6HCAPO4-,6H        ,
             B        6HMGHPO4,6H          ,6HNH2COO,6H-         ,6HKSO4- ,6H        ,
             C        6HCA(OH),6H2(S)      ,6HCACO3(,6HS)        ,6HCA3PO4,6H2(S)    ,
             D        6HCASO4(,6HS)2W      ,6HMG(OH),6H2(S)      ,6HMGCO3.,6H5H2O    ,
             E        6HSEPIOL,6HITE       ,6HCAH2SI,6HO4        ,6HSIO2(S,6H)       ,
             F        6HCA++  ,6H          ,6HMG++   ,6H         ,6HNA+   ,6H        ,
             G        6HNH4+  ,6H          ,6HK+     ,6H         ,6HCL-   ,6H        ,
             H        6HCO3=  ,6H          ,6HNO3-   ,6H         ,6HSO4=  ,6H        ,
             I        6HH4SIO4,6H          ,6HPO4---,6H          ,6HH2O   ,6H        ,
             J        6HCAHPO4,6H(S)       ,6HCASO4(,6HS)ANH /

              DO 10 I=1,30
              YM(I)=YYM(I)
           10 CONTINUE
              DO 20 I=1,30
              PP(I)=PPP(I)
           20 CONTINUE
              DO 30 I=1,35
              IOPT(I)=IIOPT(I)
           30 CONTINUE
              PH=PPH
              TK=TTK
              L0=IIOPT(1)
              L1=IIOPT(2)
```

```
      IF (L1.NE.0) AN(2)=0.
      L2=IIOPT(3)
      IF (L2.NE.0) AN(3)=.0
      L3=IIOPT(4)
      IF (L3.NE.0) CAT(5)=.0
      L34=IIOPT(16)
      CALL YEQ004 (SPECES,SOLIDS,ANTAB,CAT,AN,ICAT,IAN)
      IF (NCAT+NAN.EQ.0) RETURN
      CALL YEQ002 (PP,PH,TK,IOPT)
      TC=TK-273.16
      IF(IFLAG .EQ. 0) WRITE(6,210)
      IF(IFLAG .EQ. 0) WRITE(6,230) TC
      NCATP1=NAVCAT+1
      IF(IFLAG .EQ. 0) WRITE(6,220) (CAT(I),AN(I), I = 1,NAVCAT)
      IF(IFLAG .EQ. 0 .AND. L0 .EQ.1) WRITE(6,360) PH
      IF(IFLAG .EQ. 0 .AND. L1 .EQ.1) WRITE(6,300) PP(1)
      IF(IFLAG .EQ. 0 .AND. L2 .EQ.1) WRITE(6,310) PP(2)
      IF(IFLAG .EQ. 0 .AND. L3 .EQ.1) WRITE(6,290) PP(3)
      IF(IFLAG .EQ. 0 .AND. L34.EQ.1) WRITE(6,350)
C
C
      CH=CAT(1)+.5*AN(1)+2.*AN(5)
      CALL YEQ005 (CAT,AN)
      IF(IFLAG .EQ. 0) WRITE(6,240)
C
      N=NUMI+NUMD-NAN
      J=1
      K=2
      DO 60 I=1,N
      IF (SPECES(I).GT.0) GO TO 40
      NDEX=-SPECES(I)
      JJ=IV(J)
      G=EXP(GLN(JJ))
      A=YM(JJ)*G
      NDEX=2*NDEX-1
      IF(IFLAG .EQ. 0) WRITE(6,330)
      IF(IFLAG .EQ. 0) WRITE(6,250) LB(NDEX),LB(NDEX+1),YM(JJ),A,G
      J=J+1
      GO TO 60
   40 CONTINUE
      NDEX=SPECES(I)
      IF (SPECES(I).NE.57) GO TO 50
      G=EXP(GW)
      NDEX=2*NDEX-1
      IF(IFLAG .EQ. 0) WRITE(6,260) LB(NDEX),LB(NDEX+1),G
      GO TO 60
   50 CONTINUE
      KK=ID(K)
      G=EXP(GLND(KK))
      A=XM(KK)*G
      NDEX=2*NDEX-1
      IF(IFLAG .EQ. 0) WRITE(6,250) LB(NDEX),LB(NDEX+1),XM(KK),A,G
      K=K+1
   60 CONTINUE
C
      IF(IFLAG .EQ. 0) WRITE(6,330)
      G=EXP(GLND(1))
      A=XM(1)*G
      IF(IFLAG .EQ. 0) WRITE (6,250) LB(3),LB(4),XM(1),A,G
C
      IF (NAN.EQ.0) GO TO 80
      DO 70 I=1,NAN
      N=2*IAN(I)-1
      NDEX=ANTAB(N)*2-1
      JJ=IV(J)
      G=EXP(GLN(JJ))
      A=YM(JJ)*G
      IF(IFLAG .EQ. 0) WRITE(6,250) LB(NDEX),LB(NDEX+1),YM(JJ),A,G
      J=J+1
   70 CONTINUE
   80 CONTINUE
C
      IF (NS.EQ.0) GO TO 100
      IF(IFLAG .EQ. 0) WRITE(6,330)
      IF(IFLAG .EQ. 0) WRITE(6,340)
      IF(IFLAG .EQ. 0) WRITE(6,330)
      DO 90 I=1,NS
      NDEX=2*SOLIDS(I)-1
      III=ISK(I)
      II=III-LOCSDS+1
      YMS=YM(III)
      IF (YM(III).LE.1.E-10) YMS=0.
      RSLN=AMIN1((APS(II)-CKS(II)),80.)
      A=EXP(RSLN)
      IF (II.EQ.1.OR.II.EQ.6) APS(II)=APS(II)+2*CK(1)
      IF (II.EQ.8) APS(II)=APS(II)+4.*CK(1)
      IF(II.EQ.9) RSLN=AMIN1((APS(II)-CKS(II)+CK(5)),80.)
      B=EXP(APS(II))
      IF(IFLAG .EQ. 0) WRITE(6,250) LB(NDEX),LB(NDEX+1),YMS,B,A
   90 CONTINUE
  100 CONTINUE
      WRITE(6,330)
      MLCWTR=CH/BETA
      XMW=MLCWTR
      GW=EXP(GW)
C
C
C
      PP(1)=XM(2)*EXP(GLND(2)-PCK(1))/GW
      PP(2)=XM(4)*EXP(GLND(4)-PCK(2))
      PP(3)=XM(22)*EXP(GLND(22)-PCK(3))
      IF (L1.EQ.0) GO TO 110
      AN(2)=CH*TH(NAVCAT+2)/BETA
      IF(IFLAG .EQ. 0) WRITE(6,370)  AN(2)
      GO TO 120
  110 CONTINUE
      IF(IFLAG .EQ. 0 .AND. AN(2) .NE. .0) WRITE(6,300) PP(1)
  120 CONTINUE
      IF (L2.EQ.0) GO TO 130
      AN(3)=CH*TH(NAVCAT+3)/BETA
      IF(IFLAG .EQ. 0) WRITE(6,390) AN(3)
      GO TO 140
  130 CONTINUE
      IF(IFLAG .EQ. 0 .AND. AN(3) .NE. .0) WRITE(6,310) PP(2)
  140 CONTINUE
      IF (L3.EQ.0) GO TO 150
      CAT(5)=CH*TH(5)/BETA
      IF(IFLAG .EQ. 0) WRITE(6,380) CAT(5)
      GO TO 160
  150 CONTINUE
      IF(IFLAG .EQ. 0 .AND. CAT(5) .NE. .0) WRITE(6,290) PP(3)
  160 CONTINUE
      IF(IFLAG .EQ. 0) WRITE(6,270) MLCWTR
      PH=-ALOG10(YM(1)*EXP(GLN(1)))
      IF(IFLAG .EQ. 0) WRITE(6,280) FI,REN
      IF(IFLAG .EQ. 0 .AND. L0 .NE. 1) WRITE(6,320) PH
      DO 170 I=1,4
      PPP(I)=PP(I)
  170 CONTINUE
```

```
C
C
C
      IFLG=0
      NAVTOT=NAVCAT+NAVAN
      DO 180 I = 1,NAVSOL
      IF (IIOPT(I+20).EQ.0) GO TO 180
      NDEX=IRT(I)
      A=YM(NAVTOT+I)*XMW-XNI(I)
      IF(IFLAG .EQ. 0 .AND. IFLG .EQ. 0) WRITE(6,400)
      IFLG=1
      IF(IFLAG .EQ. 0) WRITE(6,250) LB(NDEX),LB(NDEX+1),XNI(I),BB(I),A
  180 CONTINUE
      PPH=PH
      DO 190 I=1,30
      YYM(I)=YM(I)
      XXM(I)=XM(I)
  190 CONTINUE
      DO 200 I=31,100
      XXM(I)=XM(I)
  200 CONTINUE
      RETURN
C
  210 FORMAT (1H1)
  220 FORMAT (44X,21HINPUT SPECIES (MOLES),//,30X,7HH2O  = ,1PE10.4,15X,
     17HHCL  = ,1PE10.4,/,30X,7HCAO  = ,1PE10.4,15X,7HCO2  = ,1PE10.4,/,
     230X,6HMGO = ,E10.4,15X,7HNO3- = ,E10.4/30X,6HNA+ = ,E10.4,15X,6HSO
     33 = ,E10.4/30X,7HNH3  = ,1PE10.4,15X,7HSIO2 = ,E10.4/30X,5HK+ = ,E
     410.4,15X,8HPO4=- = ,E10.4)
  230 FORMAT (1H+,70X,11HTEMPERATURE,F10.3,8H DEG. C.)
  240 FORMAT (38X,27HAQUEOUS SOLUTION EQUILIBRIA,//21X,69HCOMPONENT
     1    MOLALITY             ACTIVITY    ACTIVITY COEFFICIENT)
  250 FORMAT (22X,A6,A4,1PE15.3,4X,1PE15.3,1PE18.3)
  260 FORMAT (22X,A6,A4,34X,1PE18.3)
  270 FORMAT (/38X,18HMOLECULAR WATER = ,1PE10.4,5H KGS.)
  280 FORMAT (/36X,17HIONIC STRENGTH = ,1PE10.4,7X,12HRES. E.N. = ,1PE10
     1.3)
  290 FORMAT (22X,7HPNH3 = ,1PE10.4,2X,4HATM.)
  300 FORMAT (22X,7HPCO2 = ,1PE10.4,2X,4HATM.)
  310 FORMAT (22X,8HPHNO3 = ,1PE10.4,2X,4HATM.)
  320 FORMAT (1H+,14X,5HPH = ,F7.4)
  330 FORMAT (1H )
  340 FORMAT (21X,9HCOMPONENT,9X,8HMOLALITY,7X,37HACTIVITY PRODUCT  RELA
     1TIVE SATURATION)
 350  FORMAT (/,22X,23HSUPERSATURATION ALLOWED/)
 360  FORMAT (22X,5HPH = ,F7.4,/)
 370  FORMAT (22X,7HCO2  = ,1PE10.4,2X,5HMOLES)
 380  FORMAT (22X,6HNH3 = ,1PE10.4,2X,5HMOLES)
 390  FORMAT (22X,7HN2O5 = ,1PE10.4,2X,5HMOLES)
 400  FORMAT (/,47X,15HRATE PARAMETERS,//,21X,9HCOMPONENT,8X,10HINPUT RA
     1TE,8X,13HRATE CONSTANT,6X,13HPRECIPITATION,/,39X,9HGMOLE/SEC,10X,1
     20HKG H2O/SEC,6X,15HRATE, GMOLE/SEC,/)
      END

@PRT,S     X.YEQ004/
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```
              COMPILER (STD=66)
              SUBROUTINE YEQ004 (SPECES,SOLIDS,ANTAB,CAT,AN,ICAT,IAN)
       C
       C
       C
       C
       C
       C
       C
              REAL          NHY
       C
              DIMENSION     CAT(1)       ,AN(1)        ,ICAT(1)      ,IAN(1)
       C
              COMMON /COUNTS/NAVCAT      ,NAVAN        ,NAVSOL       ,NCAT
             1 ,NAN         ,NAVSPE
       C
              COMMON /FUNC  /F(30)       ,CK(100)      ,CT(30)       ,PCK(30)
       C
              COMMON /NAMES /NUMI        ,NUMD         ,ID(100)      ,IV(30)
             1 ,IPHI(30)    ,NEQ         ,NS           ,NEQL
       C
              COMMON /OPTN  /PP(30)      ,PH           ,TK           ,IOPT(35)
       C
              COMMON /SOLIDS/LOCSDS      ,CKS(30)      ,NHY(30)      ,ESK(30,30)
             1 ,ISK(30)     ,APS(30)
       C
              INTEGER       COMTAB(400) ,CATTAB(20)   ,ANTAB(20)    ,SPECES(100)
             1 ,SOLIDS(10)
       C
              DATA COMTAB/1,0,1,57,1,2,2,3,1,2,3,4,1,3,4,5,1,5,5,6,1,4,6,7,1,5,7
             1,8,2,0,8,9,2,2,9,10,2,2,10,11,2,3,11,12,2,4,12,13,3,0,13,14,3,2,14
             2,15,3,2,15,16,3,4,16,17,4,0,17,18,4,2,18,19,4,2,19,20,4,3,20,21,4,
             34,21,22,5,0,22,23,5,4,23,24,5,4,24,25,5,2,25,26,5,2,26,27,1,6,27,2
             48,1,6,28,29,1,6,29,30,2,6,30,31,2,6,31,32,2,6,32,33,3,6,33,34,5,2,
             534,35,6,4,35,36,2,0,1,-37,2,2,2,-38,2,6,3,-39,2,4,5,-40,3,0,6,-41,
             63,2,7,-42,3,5,8,-43,2,5,9,-44,1,5,10,-45,2,6,11,-58,2,4,4,-59/
              DATA CATTAB/1,1,46,2,47,3,48,4,49,5,50,6,8*0/
       C
              NTAB=1
              ISPEC=0
              TEMPN=0
              NUMI=1
```

```
      NUMD=0
      NEQ=1
      NSOL=0
      L0=IOPT(1)
      L1=IOPT(2)
      L2=IOPT(3)
      L3=IOPT(4)
C
C
      NCAT=1
      ICAT(1)=1
      IV(1)=1
      IPHI(1)=1
      DO 20 I=2,NAVCAT
      IF (I.EQ.5.AND.L3.NE.0) GO TO 10
      IF (CAT(I).EQ.0.) GO TO 20
   10 CONTINUE
      NCAT=NCAT+1
      ICAT(NCAT)=I
      NUMI=NUMI+1
      IV(NUMI)=I
   20 CONTINUE
C
      NAN=0
      DO 40 I=1,NAVAN
      IF ((I.EQ.2.AND.L1.NE.0).OR.(I.EQ.3.AND.L2.NE.0)) GO TO 30
      IF (AN(I).EQ.0.) GO TO 40
   30 CONTINUE
      NAN=NAN+1
      IAN(NAN)=I
      NUMI=NUMI+1
      IV(NUMI)=I+NAVCAT
   40 CONTINUE
      NEQL=NEQ
C
      DO 80 I=1,NCAT
      ISPEC=ISPEC+1
      NDEX=ICAT(I)*2-1
      SPECES(ISPEC)=-CATTAB(NDEX)
      INAN=NAN+1
      DO 70 J=1,INAN
      NTAB=-3
      ITAN=0
      IF (J.NE.1) ITAN=IAN(J-1)
   50 CONTINUE
      NTAB=NTAB+4
      IF (COMTAB(NTAB).LE.0) GO TO 70
      IF (.NOT.(COMTAB(NTAB).EQ.ICAT(I).AND.COMTAB(NTAB+1).EQ.ITAN)) GO
     1TO 50
      IF (COMTAB(NTAB+3).LE.0) GO TO 60
C
      ISPEC=ISPEC+1
      NUMD=NUMD+1
      SPECES(ISPEC)=COMTAB(NTAB+3)
      ID(NUMD)=COMTAB(NTAB+2)
      GO TO 50
C
   60 CONTINUE
      IF (IOPT(18).EQ.0.AND.COMTAB(NTAB+3).EQ.-59) GO TO 50
      IF (IOPT(18).NE.0.AND.COMTAB(NTAB+3).EQ.-40) GO TO 50
C
      NSOL=NSOL+1
      SOLIDS(NSOL)=-COMTAB(NTAB+3)
      ISK(NSOL)=COMTAB(NTAB+2)+NAVCAT+NAVAN
      GO TO 50
   70 CONTINUE
   80 CONTINUE
      IV(NUMI+1)=0
      ID(NUMD+1)=0
      SOLIDS(NSOL+1)=0
      NS=NSOL
      RETURN
      END

@PRT,S     X.YEQ005/
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```
390-1514*ASH(1).YEQ005(44)
      COMPILER (STD=66)
      SUBROUTINE YEQ005 (CAT,AN)
C
      REAL           NU          ,NEWK        ,NHY
C
      INTEGER        SPSTAT
C
      COMMON /NAMES /NUI         ,NUMD        ,ID(100)     ,IV(30)
     1 ,IPHI(30)    ,NEQ         ,NS          ,NEQL
C
      COMMON /GAMD  /DGLN(30)    ,DGLND(100)  ,IZI(30)     ,IZD(100)
C
      COMMON /GAM   /GLN(30)     ,GLND(100)   ,GW          ,FI
     1 ,GAMLN(130)  ,DGAMLN(130)
C
      COMMON/GAMMCF/GD(100),BD(100),UD(100),AI(30),BI(30)
      COMMON/BROMLY/BRMI(50),BRPL(50),DMI(50),DPL(50),BR(50,50),
     $ JMI(50),IPL(50),NPL,NMI,Z(130)
      COMMON /NWBAS /XYM(130)    ,C(100,30)   ,B(30,30)    ,NEWK(100)
     1 ,ORIGK(100)  ,NEWIND(30)  ,SPSTAT(130) ,NU(100,30)  ,NEWB
     2 ,NDTOT       ,NVTOT       ,NTP1        ,IOP1        ,NUMI
     3 ,ISKIP(100)
C
      COMMON /COUNTS/NAVCAT      ,NAVAN       ,NAVSOL      ,NCAT
     1 ,NAN         ,NAVSPE
C
      COMMON /FUNC  /F(30)       ,CK(100)     ,CT(30)      ,PCK(30)
C
      COMMON /EQVAL /TH1         ,TH2         ,BETA        ,ETA(100,30)
     1 ,TH(30)
C
      COMMON /SOLIDS/LOCSDS      ,CKS(30)     ,NHY(30)     ,ESK(30,30)
     1 ,ISK(30)     ,APS(30)
C
      COMMON /VARBLE/YM(30)      ,XM(100)     ,Y(30)
C
      COMMON /H2O   /TOTH
C
      COMMON /TRFR  /XMWPR
C
      COMMON /RESEN /REN
      COMMON/NUM/NUMIPR
```

```
C
      COMMON /OPTN  /P(30)        ,PH           ,TK           ,IIOPT(35)
C
      COMMON /RATE  /XNI(30)      ,RB(30)       ,RK(30)       ,RM(30)
C
      COMMON /APDRVR/APD(30)
C
      DIMENSION      HYD(100)     ,PRY(30)      ,ECTPR(30)    ,ECT(30)
     1 ,RHS(50,1)    ,IGAS(4)     ,IAN(4)       ,CAT(1)       ,AN(1)
     2 ,DE(30)       ,AD(30)      ,HGAS(4)
C
      DATA HGAS/1.,3*.0/
      DATA MAXIT/50/
      DATA BETAPR/55.50622/
      DATA NUMIPR/0/
      DATA ITPRT/40/
      DATA ECT(1)/.0/
      DATA IGAS/2,4,22,0/
      DATA  IAN/2,3,0,0/
      DO 10 I=1,30
      APD(I)=1.0
   10 CONTINUE
      IOP1=IIOPT(1)
      BETA=BETAPR
      IZ=1+IOP1
      NUMI1=NUI
      NUMI=NUMI1-IOP1
C
      DO 30 I=2,NUMI1
      II=IV(I)
      IF (II.GT.NAVCAT) GO TO 20
      ECT(I)=AMAX1(1.E-8,CAT(II))
      GO TO 30
   20 CONTINUE
      ECT(I)=AMAX1(1.E-8,AN(II-NAVCAT))
   30 CONTINUE
      XMW=TOTH/BETAPR
C
      IF (NUMI1.EQ.NUMIPR.AND.IIOPT(20).EQ.0.AND.IIOPT(19).EQ.0) GO TO 2
     150
C
   40 CONTINUE
      DO 70 J=1,NUMI1
      I=IV(J)
      B(J,1)=IZI(I)
      DO 60 K=2,NUMI1
      IF (J.NE.K) GO TO 50
      B(K,K)=1.
      GO TO 60
   50 CONTINUE
      B(J,K)=.0
   60 CONTINUE
   70 CONTINUE
      DO 80 I=1,100
      ISKIP(I)=0
   80 CONTINUE
C
C
C
C
C
C
      DO 95 II=1,NUMD
C
      I=ID(II)
      HYD(II)=ETA(I,1)
      ORIGK(II)=-CK(I)
      NEWK(II)=-CK(I)
      SPSTAT(II)=1
      DO 90 JJ=1,NUMI1
      J=IV(JJ)
C
      NU(II,JJ)=ETA(I,J)
   90 CONTINUE
   95 CONTINUE
      ORIGK(1)=-ORIGK(1)
      NEWK(1)=-NEWK(1)
      NDTOT=NUMD+NS
      NDP1=NUMD+1
C
      IF (NS.EQ.0) GO TO 110
      DO 105 II=NDP1,NDTOT
      I=ISK(II-NUMD)-LOCSDS+1
      HYD(II)=-NHY(I)
      ORIGK(II)=-CKS(I)-ALOG(APD(I))
      NEWK(II)=ORIGK(II)
      SPSTAT(II)=2
      DO 100 JJ=1,NUMI1
      AD(I)=1.
      J=IV(JJ)
      NU(II,JJ)=ESK(I,J)
  100 CONTINUE
  105 CONTINUE
  110 CONTINUE
      DO 120 I=1,NDTOT
      XYM(I)=1.E-8
  120 CONTINUE
      NGAS=0
      DO 140 I=1,4
C
      IF (IIOPT(I+1).EQ.0) GO TO 140
      NGAS=NGAS+1
      NDTOT=NDTOT+1
      HYD(NDTOT)=HGAS(I)
      IG=IGAS(I)
      ORIGK(NDTOT)=-PCK(I)-CK(IG)-ALOG(P(I))
      NEWK(NDTOT)=ORIGK(NDTOT)
      SPSTAT(NDTOT)=2
      XYM(NDTOT)=200.
      DO 130 J=1,NUMI1
      JJ=IV(J)
      NU(NDTOT,J)=ETA(IG,JJ)
  130 CONTINUE
  140 CONTINUE
      NTP1=NDTOT+1
      NVTOT=NDTOT+NUMI1
      DO 160 I=NTP1,NVTOT
C
      HYD(I)=.0
      ORIGK(I)=.0
      NEWK(I)=.0
      NEWIND(I-NDTOT)=I
C
      DO 150 K=1,NUMI1
      C(I,K)=B(I-NDTOT,K)
  150 CONTINUE
      SPSTAT(I)=3
  160 CONTINUE
      DO 177 I=1,NDTOT
      DO 175 K=1,NUMI1
      C(I,K)=0.
      DO 170 J=1,NUMI1
C
      C(I,K)=C(I,K)+NU(I,J)*B(J,K)
 170  CONTINUE
 175  CONTINUE
 177  CONTINUE
      I=1
      J=1
      NPL=0
      NMI=0
      DO  1780  IT = 1,NVTOT
      Z(IT)= ABS(C(IT,1))
      IF(Z(IT) .LT. .1) C(IT,1) = .0
      IF(C(IT,1))1771,1780,1775
1771  JMI(J) = IT
      IF(IT .LE. NUMD) GO TO 1772
      II = IV(IT-NDTOT)
      BRMI(J) = AI(II)
      DMI(J) = BI(II)
      GO TO 1773
1772  II = ID(IT)
      BRMI(J) = GD(II)
      DMI(J) = BD(II)
1773  J = J + 1
      NMI = NMI + 1
      GO TO 1780
1775  IPL(I) = IT
      IF(IT .LE. NUMD) GO TO 1776
      II = IV(IT-NDTOT)
      BRPL(I) = AI(II)
      DPL(I) = BI(II)
      GO TO 1778
1776  II = ID(IT)
      BRPL(I) = GD(II)
      DPL(I) = BD(II)
1778  I = I + 1
      NPL = NPL+1
1780  CONTINUE
      DO 1790 I = 1,NPL
      DO 1790 J = 1,NMI
1790  BR(I,J) = BRPL(I) + BRMI(J) + DPL(I)*DMI(J)
```

```
      IF (IIOPT(1).EQ.0) GO TO 190
C
      ISKIP(1)=1
      ISKIP(NTP1)=1
      DO 180 I=1,NDTOT
      IF (NU(I,1).EQ..0) GO TO 180
      ORIGK(I)=ORIGK(I)-NU(I,1)*2.302585*PH
      NEWK(I)=ORIGK(I)
  180 CONTINUE
  190 CONTINUE
      IF (IIOPT(19).NE.0.OR.NUMI1.NE.NUMIPR) GO TO 320
C
      DO 220 I=1,NVTOT
      IF (I.GT.NUMD) GO TO 200
      IDD=ID(I)
      XYM(I)=XM(IDD)
      GO TO 220
  200 CONTINUE
      IF (I.GT.NDTOT) GO TO 210
      IF (I-NUMD.GT.NS) GO TO 220
      IS=ISK(I-NUMD)
      XYM(I)=YM(IS)
      GO TO 220
  210 CONTINUE
      IVV=IV(I-NDTOT)
      XYM(I)=YM(IVV)
  220 CONTINUE
      DO 240 J=1,NUMI1
      ECTPR(J)=.0
      DO 230 I=1,NVTOT
      IF (XYM(I).LT.100.) ECTPR(J)=ECTPR(J)+C(I,J)*XYM(I)
  230 CONTINUE
      ECTPR(J)=ECTPR(J)*XMWPR
  240 CONTINUE
      CALL YEQU07
  250 CONTINUE
      RTOTH=XMW/XMWPR
      IF (ABS(RTOTH-1.).LT.1.E-5) GO TO 270
      DO 260 I=1,NVTOT
      IF (XYM(I).LT.100.) XYM(I)=XYM(I)/RTOTH
  260 CONTINUE
C
  270 CONTINUE
```

```
      DO 290 J=1,NUMI
      SUM=.0
      DO 280 II=1,NUMI
      I=NEWIND(II)
      B(J,II)=C(I,J+IOP1)
      SUM=SUM+C(I,J+IOP1)*XYM(I)
  280 CONTINUE
      RHS(J,1)=ECT(J+IOP1)-ECTPR(J+IOP1)+SUM*XMW
  290 CONTINUE
      CALL YEQU09 (B,NUMI,RHS,1,SING)
      DO 300 II=1,NUMI1
      I=NEWIND(II)
      IF (RHS(II,1).LT.1.E-8) GO TO 310
      XYM(I)=RHS(II,1)/XMW
  300 CONTINUE
      GO TO 360
  310 CONTINUE
      WRITE(6,650)
      IIOPT(19)=1
      GO TO 40
  320 CONTINUE
      II=NDTOT+2
C
      XYM(NTP1)=.0
      DO 330 I=2,NUMI1
      XYM(II)=ECT(I)/XMW
      IVV=IV(I)
      XYM(NTP1)=XYM(NTP1)-B(I,1)*XYM(II)
      II=II+1
  330 CONTINUE
      DO 340 I=1,100
      XM(I)=.0
  340 CONTINUE
      IF (ABS(XYM(NTP1)).LT.1.E-8) XYM(NTP1)=1.E-8
      IF (XYM(NTP1).GT..0) GO TO 350
C
      XYM(1)=-XYM(NTP1)
      XYM(NTP1)=1.E-8
  350 CONTINUE
      NEWB=NGAS
  360 CONTINUE
      DO 520 ITER=1,MAXIT
      CALL YEQU06
      IF (NEWB.NE.0.OR.(IOP1.NE.0.AND.ITER.EQ.1)) CALL YEQ007
      NEWB=0
      IF (IOP1.EQ.0) GO TO 370
C
      SPSTAT(NTP1)=3
      XYM(NTP1)=EXP(-2.302585*PH-GAMLN(NTP1))
      XYM(1)=EXP(ORIGK(1)+GW-GAMLN(1))
  370 CONTINUE
      NOCVG=0
      IF (ITER.GE.ITPRT) WRITE(6,660) ITER
C
      DO 470 I=IZ,NVTOT
      IF (SPSTAT(I).GT.2) GO TO 470
      IF (SPSTAT(I).EQ.2.AND.IIOPT(16).NE.0) GO TO 470
      QLN=.0
      DQDXI=.0
      IF (SPSTAT(I).EQ.2) GO TO 380
      QLN=ALOG(XYM(I))+GAMLN(I)
      DQDXI=1./XYM(I)
      GO TO 390
  380 CONTINUE
      IF (NS.EQ.0.OR.(I-NUMD).GT.NS) GO TO 390
      IS=ISK(I-NUMD)-LOCSDS+1
      IF (IIOPT(IS+20).EQ.0) GO TO 390
C
      DENOM=(TOTH/BETA+RB(IS))*XYM(I)-XNI(IS)
      EFFAPD=RB(IS)*XYM(I)/DENOM
      IF (EFFAPD.LE..0) GO TO 390
      QLN=QLN-ALOG(EFFAPD)
      DQDXI=DQDXI+XNI(IS)/XYM(I)/DENOM
C
  390 CONTINUE
      DO 410 J=1,NUMI
      IF (NU(I,J).EQ..0) GO TO 410
      K=NEWIND(J)
      IF (SPSTAT(K).EQ.3) GO TO 400
      IF (HYD(K).NE..0) QLN=QLN-HYD(K)*GW*NU(I,J)
      IF (NS.EQ.0.OR.(K-NUMD).GT.NS) GO TO 410
      IS=ISK(K-NUMD)-LOCSDS+1
      IF (IIOPT(IS+20).EQ.0) GO TO 410
C
      DE(IS)=(TOTH/BETA+RB(IS))*XYM(K)-XNI(IS)
      AD(IS)=RB(IS)*XYM(K)/DE(IS)
      IF (AD(IS).LE.1.E-20) GO TO 410
      QLN=QLN+ALOG(AD(IS))*NU(I,J)
      DQDXI=DQDXI+XNI(IS)/XYM(K)/DE(IS)*NU(I,J)**2
      GO TO 410
  400 CONTINUE
      QLN=QLN-NU(I,J)*(ALOG(XYM(K))+GAMLN(K))
      IF (SPSTAT(I).NE.0) DQDXI=DQDXI+NU(I,J)**2/XYM(K)
  410 CONTINUE
      IF (HYD(I).LT..0) QLN=QLN+HYD(I)*GW
      IF (SPSTAT(I).EQ.2.AND.XYM(I).LT.1.E-6.AND.QLN.GT.NEWK(I)) GO TO 4
     170
      IF (DQDXI.NE..0) GO TO 430
C
      DELXI=XYM(I)
      DO 420 JJ=1,NUMI
      IF (NU(I,JJ).EQ..0) GO TO 420
      J=NEWIND(JJ)
      DELXI=AMIN1(DELXI,XYM(J)/ABS(NU(I,JJ)))
  420 CONTINUE
      DXMAX=SIGN(DELXI,NEWK(I)-QLN)
      GO TO 450
C
  430 CONTINUE
      DELXI=(NEWK(I)-QLN)/DQDXI
      DXMAX=DELXI
C
      IF (DXMAX.LT..0) DXMAX=-AMIN1(-DXMAX,.99*XYM(I))
      DXNU=ABS(DXMAX)
      DO 440 JJ=1,NUMI
      IF (ABS(NU(I,JJ)).LT.1.E-4) GO TO 440
      J=NEWIND(JJ)
C
      DXIND=ABS(.5*XYM(J)/NU(I,JJ))
      IF (DXNU.LT.DXIND) GO TO 440
      DXNU=DXIND
      DXMAX=SIGN(DXNU,DELXI)
  440 CONTINUE
  450 CONTINUE
      XYM(I)=XYM(I)+DXMAX
      DELXI=DXMAX
      DO 460 JJ=1,NUMI
      J=NEWIND(JJ)
      XYM(J)=XYM(J)-NU(I,JJ)*DELXI
  460 CONTINUE
      IF (ITER.GE.ITPRT) WRITE(6,670) I,NEWK(I),QLN,DQDXI,DELXI,XYM(I)
  470 CONTINUE
C
      DO 480 J=1,NUMI
      JJ=NEWIND(J)
      IF(XYM(JJ).EQ.0.0) XYM(JJ)=.000000001
      IF (ABS(XYM(JJ)-PRY(J))/XYM(JJ).GT.5.E-5) NOCVG=1
      PRY(J)=XYM(JJ)
  480 CONTINUE
      IF (NOCVG.EQ.0) GO TO 530
      BETA=.0
C
      DO 500 I=1,NVTOT
      IF (XYM(I).GT.100.) GO TO 500
      BETA=BETA+ABS(HYD(I))*XYM(I)
      IF (SPSTAT(I).EQ.2.OR.SPSTAT(I).EQ.4) BETA=BETA+ABS(HYD(I))*XYM(I)
      IF (SPSTAT(I).GT.2.OR.ISKIP(I).NE.0) GO TO 500
      NOMINR=0
      DO 490 J=1,NUMI
      IF (NU(I,J).EQ..0) GO TO 490
      JJ=NEWIND(J)
      IF (XYM(I).GT.XYM(JJ)) NEWB=1
      IF (XYM(I).GT..01*XYM(JJ)) NOMINR=1
  490 CONTINUE
      IF (NOMINR.EQ.1.AND.SPSTAT(I).EQ.0) SPSTAT(I)=1
      IF (NOMINR.EQ.0.AND.ITER.GT.4.AND.SPSTAT(I).NE.2) SPSTAT(I)=0
  500 CONTINUE
      BETA=.5*(BETA+XYM(NTP1))+55.50622
      RBETA=BETA/BETAPR
      DO 510 I=1,NVTOT
      XYM(I)=RBETA*XYM(I)
  510 CONTINUE
      BETAPR=BETA
  520 CONTINUE
      WRITE (6,680) MAXIT
      CALL EXIT
  530 CONTINUE
      REN=.0
      DO 560 I=1,NVTOT
      IF (C(I,1).NE..0) REN=REN+C(I,1)*XYM(I)
C
      IF (I.GT.NUMD) GO TO 540
      IX=ID(I)
      XM(IX)=XYM(I)
      GLND(IX) = GAMLN(I)
      GO TO 560
  540 CONTINUE
      IF (I.GT.NDTOT) GO TO 550
      IF (I-NUMD.GT.NS) GO TO 560
      IS=ISK(I-NUMD)
      YM(IS)=XYM(I)
      IF (YM(IS).LT.1.E-6) YM(IS)=.0
      GO TO 560
  550 CONTINUE
      IVV=IV(I-NDTOT)
      YM(IVV)=XYM(I)
      GLN(IVV) = GAMLN(I)
  560 CONTINUE
      IF (NS.EQ.0) GO TO 590
      DO 580 IS=1,NS
      I=ISK(IS)-LOCSDS+1
      IF(I.EQ.9) GO TO 580
      SUM=.0
      DO 570 KS=1,NUMI1
      K=IV(KS)
      SUM=SUM+ESK(I,K)*(ALOG(YM(K))+GLN(K))
  570 CONTINUE
      APS(I)=SUM+NHY(I)*GW
  580 CONTINUE
      IF(YM(2).GT.0..AND.XM(5).GT.0.)
     *APS(9) = ALOG(XM(5))+GLND(5)+ALOG(YM(2))+GLN(2)+NHY(9)*GW
C
  590 CONTINUE
      IF (NGAS.EQ.0) GO TO 630
      DO 620 I=1,4
      IF (IIOPT(I+1).EQ.0) GO TO 620
      IA=IAN(I)+NAVCAT
      DO 600 II=1,NUMI1
      IF (IV(II).EQ.IA) ICOL=II
  600 CONTINUE
      SUM=.0
      DO 610 IT=1,NVTOT
      IF (XYM(IT).LT.100.) SUM=SUM+C(IT,ICOL)*XYM(IT)
  610 CONTINUE
      TH(IA)=SUM
  620 CONTINUE
  650 CONTINUE
      DO 640 I=1,NUMI1
      ECTPR(I)=ECT(I)
  640 CONTINUE
      XMWPR=TOTH/BETA
      NUMIPR=NUMI1
      RETURN
C
  650 FORMAT (47HOCANT USE PREV RESULTS, GO TO DEFAULT PROCEDURE)
  660 FORMAT (10HOITERATION,I4,39H  SPEC   LNK   LNQ   DQDXI  DELXI   XY
     1M)
  670 FORMAT (1H0,I10,5E15.6)
  680 FORMAT (18HONOCONVERGENCE IN ,I3,12H  ITERATIONS)
      END

@PRT,S     X.YEQ006/
```

```
390-1514*ASH(1).YEQ006(43)
      COMPILER (STD=66)
      SUBROUTINE YEQ006
      COMMON /NAMES /NUMI         ,NUMD         ,ID(100)      ,IV(30)
     1 ,IPHI(30)    ,NEQ          ,NS           ,NEQL
C
      COMMON /VARBLE/YM(30)       ,XM(100)      ,Y(30)
C
      COMMON /GAM   /GLN(30)      ,GLND(100)    ,GW           ,FI
     1 ,GAMLN(130)  ,DGAMLN(130)
C
      COMMON /GAMD  /DGLN(30)     ,DGLND(100)   ,IZI(30)      ,IZD(100)
C
      COMMON/BROMLY/BRMI(50),BRPL(50),DMI(50),DPL(50),BR(50,50),
     $ JMI(50),IPL(50),NPL,NMI,Z
      COMMON/TEMPER/ TC,DUMY
      COMMON/GAMMCF/AD(100),BD(100),UD(100),AI(30),BI(30)
      REAL            NU          ,NEWK
C
      COMMON /NWBAS /XYM(130)     ,C(100,30)    ,B(30,30)     ,NEWK(100)
     1 ,ORIGK(100)  ,NEWIND(30)   ,SPSTAT(130)  ,NU(100,30)   ,NEWB
     2 ,NDTOT       ,NVTOT,DUMMY(103)
C
      DIMENSION Z(130),BDOT(50,50)
      DATA AGAM/1.177/,TENLN/2.302585/
      TM=.0
      TN=.0
      FI = .0
      DO  10  I = 1,NVTOT
      IF(Z(I) .LT. .1) GO TO 10
      GAMLN(I) = .0
      TM = TM + XYM(I)
      XYZ = XYM(I)*Z(I)
      TN = TN + XYZ
       FI = FI + XYZ*Z(I)
   10 CONTINUE
      FI = .5*FI
      TM = .5*TM
      TN = .5*TN
      SRI = SQRT(FI)
      DO  30  I = 1,NPL
      K = IPL(I)
      DO  30  J = 1,NMI
      L = JMI(J)
   30 BDOT(I,J) = (BR(I,J) + (.06+.6*BR(I,J))*Z(K)*Z(L)/(1.+1.5*FI/Z(K)
     $ /Z(L))**2)*(Z(K) + Z(L))**2/4.*TENLN
      BB = .0
      DO  40  I = 1,NPL
      IP = IPL(I)
      DO  35  J = 1,NMI
      JM = JMI(J)
   35 GAMLN(IP) = GAMLN(IP) + BDOT(I,J)*XYM(JM)
   40 BB = BB + GAMLN(IP)*XYM(IP)
      DO  50  J = 1,NMI
      JM = JMI(J)
      DO  45  I = 1,NPL
      IP = IPL(I)
   45 GAMLN(JM) = GAMLN(JM) + BDOT(I,J)*XYM(IP)
   50 BB = BB + GAMLN(JM)*XYM(JM)
      BB = BB*2./TM/FI
      DO  55  I = 1,NVTOT
      IF(Z(I) .LT. .1) GO TO 55
      GAMLN(I) = -AGAM*Z(I)**2*SRI/(1. + SRI) + GAMLN(I)
   55 CONTINUE
      DO  60  I = 1,NUMD
      IF(Z(I) .GT. .1) GO TO 60
      IU = ID(I)
      DO  58  J = 1,NVTOT
      IF(Z(J) .LT. .1) GO TO 58
      GAMLN(J) = GAMLN(J) + UD(IU)*XYM(I)*Z(J)
   58 CONTINUE
      GAMLN(I) = UD(IU)*TN
   60 CONTINUE
      SIGMA = 3./SRI**3*(1.+SRI-1./(1.+SRI)-2.*ALOG(1.+SRI))
      X = .75*TM
      PSI =2./X*((1.+2.*X)/(1.+X)**2 - ALOG(1. + X)/X)
      GW = (.666667*AGAM*FI*SRI*SIGMA -        (.06+.6*BB)*FI**2*PSI
     $ - TM -        BB*FI*TM/2.)/55.506
      GAMREF = -.944*SRI/(1. + SRI) + .039*FI**.92
      SUMG = .0
      DO  70  I = 1,NVTOT
      IF(Z(I) .LT. .1) GO TO 70
      DELG = GAMLN(I) - GAMREF*Z(I)
      SUMG = SUMG + XYM(I)*DELG
      GAMLN(I)=GAMLN(I) + (.125 - .005*TC)*DELG
   70 CONTINUE
```

```
      GW = GW + .005/55.506*SUMG*(TC-25.)
      RETURN
      END

@PRT,S    X.YEQ007/
```

```
390-1514*ASH(1).YEQ007(41)
              COMPILER (STD=66)
              SUBROUTINE YEQ007
      C
              REAL           NU           ,NEWK
      C
              INTEGER        SPSTAT
      C
              DIMENSION      IORD(130)    ,TEMP(130)    ,BB(30,30)    ,DUMY(50,1)
      C
              COMMON /NWBAS /XYM(130)     ,C(100,30)    ,B(30,30)     ,NEWK(100)
             1 ,ORIGK(100)   ,NEWIND(30)  ,SPSTAT(130)  ,NU(100,30)   ,NEWB
             2 ,NDTOT        ,NVTOT       ,IHYD         ,IOP1         ,NUMI
             3 ,ISKIP(100)
      C
      C
              DO 10 I=1,NVTOT
              TEMP(I)=XYM(I)
         10   CONTINUE
              DO 30 J=1,NVTOT
              XYMAX=.0
              DO 20 I=1,NVTOT
              IF (TEMP(I).LE.XYMAX) GO TO 20
              IMAX=I
              XYMAX=XYM(I)
         20   CONTINUE
              IORD(J)=IMAX
              TEMP(IMAX)=.0
         30   CONTINUE
              L=1
              DO 80 K=1,NUMI
         40   CONTINUE
              I=IORD(L)
              IF (ISKIP(I).EQ.0) GO TO 50
              L=L+1
              GO TO 40
         50   CONTINUE
              DO 65 J=1,NUMI
      C
              B(K,J)=C(I,J+IOP1)
              DO 60 KK=1,K
              BB(J,KK)=B(KK,J)
         60   CONTINUE
```

```
   65 CONTINUE
      IF (K.GT.1) CALL YEQ008 (K,NUMI,BB,1.E-5,INGULR)
      L=L+1
      IF (L.LE.NVTOT) GO TO 70
      WRITE(6,160) K
      CALL EXIT
   70 CONTINUE
      IF (INGULR.NE.0) GO TO 40
C
      NEWIND(K)=I
   80 CONTINUE
      CALL YEQ009 (B,NUMI,DUMY,0,SING)
C
      DO 110 I=1,NVTOT
      NEWSTA=0
      DO 90 J=1,NUMI
      IF (I.EQ.NEWIND(J)) NEWSTA=1
   90 CONTINUE
      IF (NEWSTA.EQ.1) GO TO 100
      IF (SPSTAT(I).GE.3) SPSTAT(I)=SPSTAT(I)-2
      GO TO 110
  100 CONTINUE
      IF (SPSTAT(I).EQ.0) SPSTAT(I)=3
      IF (SPSTAT(I).LE.2) SPSTAT(I)=SPSTAT(I)+2
  110 CONTINUE
C
      DO 130 I=1,NVTOT
      IF (SPSTAT(I).GT.2) GO TO 130
      DO 125 K=1,NUMI
      NU(I,K)=.0
      DO 120 J=1,NUMI
      NU(I,K)=NU(I,K)+C(I,J+IOP1)*B(J,K)
  120 CONTINUE
  125 CONTINUE
  130 CONTINUE
C
      DO 150 I=1,NVTOT
      IF (SPSTAT(I).GE.3) GO TO 150
      NEWK(I)=ORIGK(I)
      DO 140 J=1,NUMI
      IF (ABS(NU(I,J)).LT.1.E-4) NU(I,J)=.0
      JJ=NEWIND(J)
      NEWK(I)=NEWK(I)-NU(I,J)*ORIGK(JJ)
```

```
 140  CONTINUE
 150  CONTINUE
      RETURN
C
 160  FORMAT (53H0NEW BASIS MATRIX CANT BE FOUND, INDEPENDENT VARIABLE,I
     15)
      END

@PRT,S    X.YEQ008/
```

```
      COMPILER (STD=66)
      SUBROUTINE YEQDDB (N,M,Y,ZERO,INGULR)
C
C
      DIMENSION      Y(30,30)     ,P(30,30)     ,T(30)
C
      INGULR=0
      W=.0
      DO 10 L=1,M
      W=W+Y(L,1)**2
   10 CONTINUE
      P(1,1)=SQRT(W)
      DO 20 L=1,M
      Y(L,1)=Y(L,1)/P(1,1)
   20 CONTINUE
      IF (N.GT.1) GO TO 30
      P(1,1)=1./P(1,1)
      RETURN
   30 CONTINUE
      DO 90 J=2,N
      W=.0
      JM1=J-1
      DO 40 I=1,JM1
      P(I,J)=.0
      DO 35 L1=1,M
      P(I,J)=P(I,J)+Y(L1,I)*Y(L1,J)
   35 CONTINUE
   40 CONTINUE
      DO 60 L=1,M
      T(L)=Y(L,J)
      DO 50 I=1,JM1
      T(L)=T(L)-P(I,J)*Y(L,I)
   50 CONTINUE
      W=W+T(L)**2
   60 CONTINUE
      IF (ABS(W).GT.ZERO) GO TO 70
      INGULR=J
      RETURN
   70 CONTINUE
      P(J,J)=SQRT(W)
      DO 80 L2=1,M
      Y(L2,J)=T(L2)/P(J,J)
   80   CONTINUE
   90   CONTINUE
        RETURN
        END

@PRT,S     X.YEQ009/
```

```
390-1514*ASH(1).YEQ009(40)
      COMPILER (STD=66)
      SUBROUTINE YEQ009 (A,N,B,M,DETERM)
      DIMENSION      IPIVOT(30)  ,A(30,30)    ,B(50,1)     ,INDEX(30,2)
     1 ,PIVOT(30)
C
      EQUIVALENCE (IROW,JROW), (ICOLUM,JCOLUM), (AMAX,T,SWAP)
C
C
C
   10 CONTINUE
      DETERM=1.0
      DO 20 J=1,N
      IPIVOT(J)=0
   20 CONTINUE
      DO 215 I=1,N
C
C
C
      AMAX=0.0
      DO 70 J=1,N
      IF (IPIVOT(J)-1) 30,70,30
   30 CONTINUE
      DO 60 K=1,N
      IF (IPIVOT(K)-1) 40,60,260
   40 CONTINUE
      IF (ABS(AMAX)-ABS(A(J,K))) 50,60,60
   50 CONTINUE
      IROW=J
      ICOLUM=K
      AMAX=A(J,K)
   60 CONTINUE
   70 CONTINUE
      IF (ABS(AMAX).LE.0.0) GO TO 250
      IPIVOT(ICOLUM)=IPIVOT(ICOLUM)+1
C
C
C
      IF (IROW-ICOLUM) 80,120,80
   80 CONTINUE
      DETERM=-DETERM
      DO 90 L=1,N
      SWAP=A(IROW,L)
```

```
                 A(IROW,L)=A(ICOLUM,L)
                 A(ICOLUM,L)=SWAP
           90    CONTINUE
                 IF (M) 120,120,100
          100    CONTINUE
                 DO 110 L=1,M
                 SWAP=B(IROW,L)
                 B(IROW,L)=B(ICOLUM,L)
                 B(ICOLUM,L)=SWAP
          110    CONTINUE
          120    CONTINUE
                 INDEX(I,1)=IROW
                 INDEX(I,2)=ICOLUM
                 PIVOT(I)=A(ICOLUM,ICOLUM)
                 DETERM=DETERM*PIVOT(I)
         C
         C
         C
                 A(ICOLUM,ICOLUM)=1.0
                 DO 130 L=1,N
                 A(ICOLUM,L)=A(ICOLUM,L)/PIVOT(I)
          130    CONTINUE
                 IF (M) 160,160,140
          140    CONTINUE
                 DO 150 L=1,M
                 B(ICOLUM,L)=B(ICOLUM,L)/PIVOT(I)
          150    CONTINUE
         C
         C
         C
          160    CONTINUE
                 DO 210 L1=1,N
                 IF (L1-ICOLUM) 170,210,170
          170    CONTINUE
                 T=A(L1,ICOLUM)
                 A(L1,ICOLUM)=0.0
                 DO 180 L=1,N
                 A(L1,L)=A(L1,L)-A(ICOLUM,L)*T
          180    CONTINUE
                 IF (M) 210,210,190
          190    CONTINUE
                 DO 200 L=1,M
                 B(L1,L)=B(L1,L)-B(ICOLUM,L)*T
```

```
  200 CONTINUE
  210 CONTINUE
  215 CONTINUE
C
C
C
      DO 240 I=1,N
      L=N+1-I
      IF (INDEX(L,1)-INDEX(L,2)) 220,240,220
  220 CONTINUE
      JROW=INDEX(L,1)
      JCOLUM=INDEX(L,2)
      DO 230 K=1,N
      SWAP=A(K,JROW)
      A(K,JROW)=A(K,JCOLUM)
      A(K,JCOLUM)=SWAP
  230 CONTINUE
  240 CONTINUE
      GO TO 260
  250 CONTINUE
      DETERM=0.0
  260 RETURN
      END
```

APPENDIX E

TECHNICAL NOTE:

RESULTS OF PLANT SAMPLING AND LABORATORY STUDIES TO INVESTIGATE RECIRCULATING ASH SLUICING SYSTEMS

DCN 80-211-004-02

TECHNICAL NOTE

RESULTS OF PLANT SAMPLING AND LABORATORY STUDIES TO INVESTIGATE RECIRCULATING ASH SLUICING SYSTEMS

EPA Contracts 68-01-5163, Task 8
68-02-3163

Submitted to

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SECTION 1

INTRODUCTION

BACKGROUND

The U. S. Environmental Protection Agency (EPA) is considering limiting the discharge of ash sluice water from power plants through the control of priority pollutants. An alternative to treatment for the removal of priority pollutants is to recycle the ash pond overflow. However, recycle of this water will cause soluble species which leach from the ash, such as calcium, magnesium, sodium, sulfate, and silica, to concentrate which may cause scale formation (calcium carbonate [$CaCO_3$] or gypsum [$CaSO_4 \cdot 2H_2O$]) and subsequent plugging in the system.

Radian Corporation, under contract to the EPA, is investigating closed-loop ash sluicing through testing of a pilot scale system. Prior to constructing the pilot unit, laboratory tests were conducted with a bench scale system to gather data to aid in designing the pilot system and to aid in preparing test plans for operation of the pilot unit.

This technical note presents the results from testing of the bench scale recirculating ash sluicing system. Fly ash from three utilities was sluiced in a laboratory apparatus to determine the feasibility of operating in a closed-loop manner. Additionally, beaker leaching tests of fly ash and bottom ash and the results of sampling process streams at three utility sites where sluicing is used are given. Finally, the bench scale results are compared with the predictions of an ash sluicing computer model.

This work was performed under EPA Contract 68-01-5163, Task 8. The scope of work included sampling the sluicing systems at three utility sites, performing leaching tests on both bottom ash and fly ash samples from these plants, operation of a bench scale recirculating ash sluicing system to define potential operating problems of a closed-loop sluicing system and developing a computer model to simulate a recirculating ash sluice operation. The pilot scale system is being built and will be tested under EPA Contract 68-02-3163. Also under EPA Contract 68-02-3163, the computer model will be modified to reflect the pilot data.

The pilot unit (200 ℓpm sluice rate) is to be tested at three utility locations to determine the feasibility of closed-loop ash sluicing systems, using sidestream treatment if necessary to prevent chemical scaling problems. The bench scale tests reported herein were performed in order to anticipate problems which could occur with recycling sluice water. Relationships between the soluble content of the various ashes and the sluice water gypsum relative saturation have been developed to help anticipate scaling problems.

SUMMARY AND CONCLUSIONS

The bench scale sluicing results and the leaching analyses were used to develop a linear relationship for each ash between the percent solids in the sluice stream and the percent blowdown required to prevent gypsum scaling in the system. The relationship is of the form $y=mx$, where y is the minimum percent of sluice water which must be blown down from the system to keep gypsum subsaturated and x is the percent suspended solids in the ash slurry stream. The parameter m was determined for each ash and is related to the amounts of soluble calcium and sulfate present in the ash. At relative saturations of 1.3-1.4, gypsum scaling has been known to occur in lime/limestone scrubbing systems. Scaling can cause plugging and ultimately necessitate shutdown for cleaning. Consequently, it is desirable to avoid conditions which promote scaling. Of the three fly ash samples studied, two required blowdown to keep the gypsum saturation below 1.0. The third ash was fairly unreactive indicating the possibility of subsaturated operation in a closed-loop mode without any sluice water treatment. In addition, both plant samples and bench scale samples were analyzed for inorganic priority pollutants.

The computer program developed under EPA contract can model ash sluicing systems in various configurations. This model was used to verify the relationships calculated from the experimental data. The agreement between the blowdown required for saturated operation obtained from the experimental results and that predicted by the computer was very good and is presented in Table 1.

Because of this agreement, it appears that the computer program will be able to estimate the amount of treatment necessary to operate the pilot scale system in a closed-loop, non-scaling mode. The computer program will be used to aid in preparing test plans for the operation of the pilot unit.

TABLE 1. COMPUTER AND BENCH SCALE PREDICTED RESULTS

Plant	Percent solids in sluice stream	Percent blowdown predicted by data to maintain gypsum saturation at 1.0	Percent blowdown input to model	Model* predicted relative saturation
1873	5.0	24.8	25	1.01
1873	5.0	24.8	35.4	.70
4424	10.0	None	.004†	.57
9677	10.0	26.8	28	1.04

*A relative saturation of 1.0 or less indicates that scaling is not anticipated to occur in the sluice system.

†A small value was required to prevent division by zero in the model.

SECTION 2

OBJECTIVES AND TEST APPROACH

This section discusses the objectives of this work and the test approach used to obtain the desired data.

OBJECTIVES

There were four major objectives of the work reported in this technical note. They were:

1) obtain samples from 3 utility sites which currently use ash sluicing and analyze for major species and 13 inorganic priority pollutants,

2) perform beaker leaching tests (in deionized water) on ash samples to determine the maximum level of soluble species present in each ash,

3) run the bench scale ash sluicing system to collect data for designing the pilot system and for use in preparing test plans for operation of the pilot system, and

4) correlate the experimental data with that predicted by the ash sluicing computer model.

The samples from the utility sites all indicate that soluble species are being leached from the sluiced ash. None of the plants operate in a closed-loop mode; consequently, there is some discharge of inorganic priority pollutants. These three plants also supplied the ash samples for the leaching and sluicing tests.

Beaker leaching tests were performed on both fly ash and bottom ash samples from each plant. Variables of the leaching study included the temperature of the fluid, the pH, and the suspended solids concentration. Additionally, one test was performed for each ash where the bottom ash sample was crushed to determine the effect of increased surface area on the soluble species concentrations.

The bench scale sluicing system was used to determine steady-state concentrations of the soluble ions leached from the ash. Three different test runs were made with each ash. Additionally, only fly ash was tested in the sluicing system. There were three reasons for not sluicing the bottom ash samples. First, bottom ash sluicing (the initial contact of ash and water) in utility boilers generally occurs at high temperatures (∿600°C). Performing these tests at ambient conditions would not give comparable results. Secondly, the beaker leaching tests indicate that the fly ash is 3-10 times more reactive than the bottom ash samples. Because the gypsum relative saturation is the product of the calcium and sulfate levels, the relative saturations of the fly ash slurry would be 10-100 times greater than a bottom ash slurry. Therefore, the fly ash sluice stream would be much more likely to cause scaling and plugging. Thirdly, the bottom ash samples would have to have been pulverized to be used in the vibratory ash hopper in the bench system, which again would not be representative of actual plant operation.

The last objective was the correlation of the experimental results with the computer model predictions. As shown in the previous section, the agreement is very good.

TEST APPROACH

Plant Samples

Plant samples were taken around the sluicing systems at the three utility sites which participated in this study. Grab samples of slurry and liquid were taken during several different sluicing periods. The samples were quickly filtered and diluted to quench any solid-liquid reactions. Dry fly ash samples were collected from the ESP hoppers. Bottom ash samples were filtered from the slurry at Plants 4424 and 9677, the only method possible. At Plant 1873, a sample was taken dry from the bottom of the boiler since the bottom ash sluice configuration permitted this sampling.

Beaker Leaching Tests

Ash leaching experiments were performed in 400 ml beakers using magnetic stirrers. Known volumes of hydrochloric acid or potassium hydrooxide were added to keep the liquor pH constant as the available alkalinity or acidity in the ash was dissolved. Samples of bottom ash and fly ash were leached. Variables examined were the liquor pH, temperature, percent solids and for the bottom ash, particle size. One sample of each bottom ash was pulverized before leaching. The results of these tests are discussed in Section 3.

Bench Scale Sluicing System

Figure 1 is a schematic of the bench scale sluicing system. Fly ash was continuously added to the mix tank from a vibratory hopper by means of a screw feeder. The ash feed rate could be varied and was used at 15 and 31 grams per minute during the test runs. The total liquid flow to the mix tank was kept at .3 liters per minute (ℓpm). This flow was a combination of makeup water and recirculated pond water. Variable speed peristaltic pumps were used to control the water flow rates to the mix tank. The ash slurry drained into the simulated ash pond by an overflow tube. Provisions for bubbling CO_2/air mixtures into the pond clear well were also included so that the effects of CO_2 absorption/desorption could be investigated.

The blowdown rate was expressed as a percentage of the total flow to the mix tank. Both rotameters and time-volume measurements were used to maintain the desired flow rates. Liquid left the system in three ways:

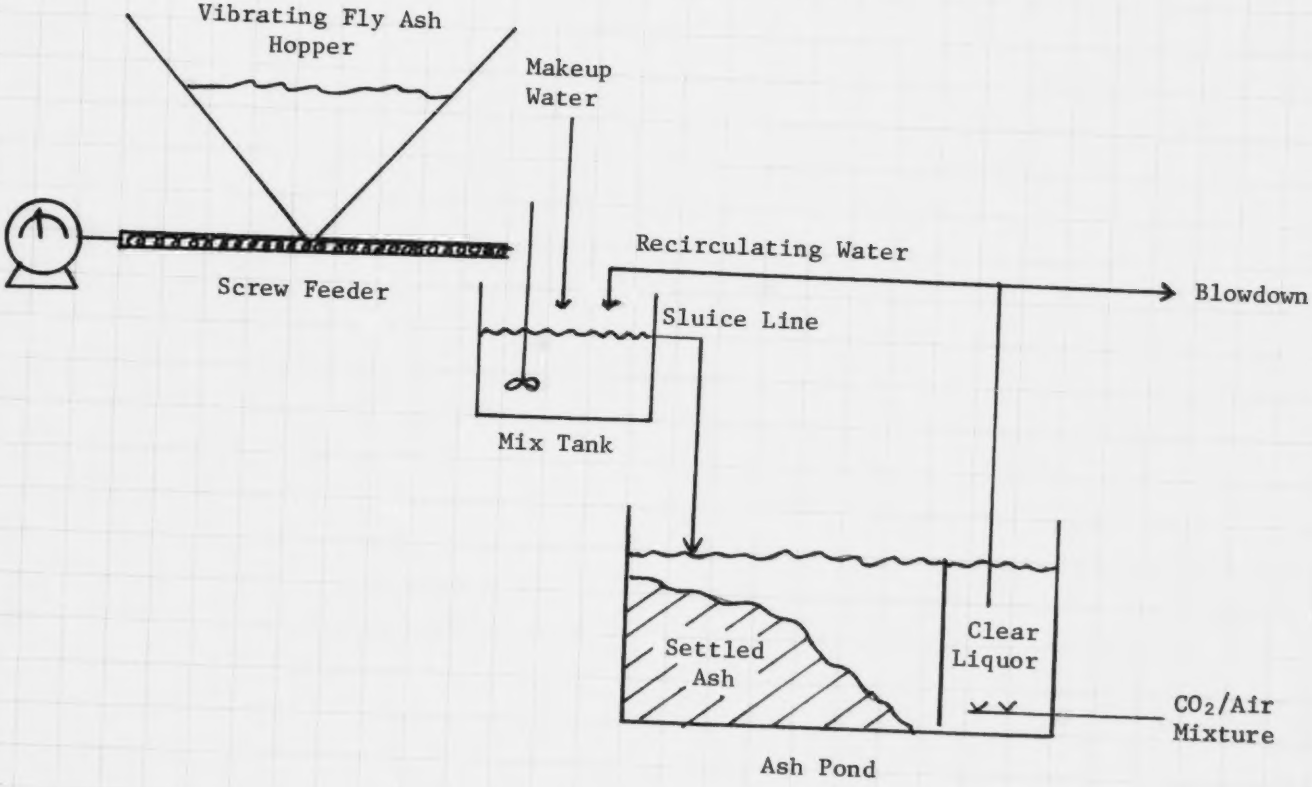

Vibrating Fly Ash
Hopper
Makeup
Water
Screw Feeder
Recirculating Water
Blowdown
Sluice Line
Mix Tank
Settled
Ash
Clear
Liquor
CO₂/Air
Mixture
Ash Pond

Figure 1. Bench scale sluicing system.

1) as a sample, 2) as blowdown, and 3) occluded in the settled solids in the ash pond. Changes in the system liquid volume were minimized to allow the system to approach steady state by matching the makeup water rate to the blowdown and occluded liquor volumes.

Prior to the testing of each ash, a 10 percent slurry was mixed in the pond to establish a working fluid and provide a "head start" in approaching steady state. Approximately 115 liters were prepared in this manner. The maximum pond volume was about 600 liters. The pond was a galvanized tank which was coated with a plastic lacquer to prevent contamination due to corrosion.

SECTION 3

RESULTS

This section presents the results of the leaching tests and the bench scale sluicing tests. The results of sampling at the three utility sites are also compared to the leaching results. The raw plant data and a brief description of each plant is given in Appendix A.

LEACHING RESULTS

Table 2 presents the conditions under which the ash samples were leached. The amount of solids leached was determined by the desired suspended solids of the slurry. Four hundred milliliters of deionized water was used as the leaching fluid. The samples were stirred for two hours or until no further change in pH was observed. A sample was then filtered and analyzed for both major species and inorganic priority pollutants. Tables 3 through 8 present the results of the leaching tests. Results are reported as milligrams leached per gram of ash.

Fly Ash Leaching Results

For Plant 1873, the fly ash leaching results are shown in Table 3. With an increase in pH, the amount of the major species leached from the ash decreased for all species except $C\ell$, which increased. With an increase in suspended solids, the amounts of Ca and SO_4 increased, but the amount of other species leached decreased. As the temperature was raised, the levels of all species but Na and K increased. However, the level of Ca leached increased by only 14 percent and the level of SO_4 leached increased by only 12 percent with an increase in temperature from 24°C to 37°C (The higher temperature was used to simulate conditions at the plant).

TABLE 2. TEST MATRIX FOR LABORATORY LEACHING TESTS

Plant	Ash	Sample	pH	Percent Solids	Temperature, °C	Particle Size
1873	Bottom	B-1	N*	0.5	Ambient	Natural
		B-2	N-1	0.5	Ambient	Natural
		B-3	N	0.5	Ambient	Crushed
		B-4	N	1.0	Ambient	Natural
		B-5	N	0.5	51	Natural
	Fly	F-1	N	5.0	Ambient	--
		F-2	N+1	5.0	Ambient	--
		F-3	N	10.0	Ambient	--
		F-4	N	5.0	37	--
4424	Bottom	B-6	N	2.0	Ambient	Natural
		B-7	N-1	2.0	Ambient	Natural
		B-8	N	2.0	Ambient	Crushed
		B-9	N	5.0	Ambient	Natural
		B-10	N	2.0	49	Natural
		B-11	N	1.0	Ambient	Natural
	Fly	F-5	N	5.0	Ambient	--
		F-6	N+1	5.0	Ambient	--
		F-7	N	2.0	Ambient	--
		F-8	N	5.0	40	--
9677	Bottom	B-12	N	1.0	Ambient	Natural
		B-13	N-1	1.0	Ambient	Natural
		B-14	N	1.0	Ambient	Crushed
		B-15	N	5.0	Ambient	Natural
		B-16	N	1.0	49	Natural
	Fly	F-9	N	5.0	Ambient	--
		F-10	N-1	5.0	Ambient	--
		F-11	N	10.0	Ambient	--
		F-12	N	5.0	40	--

*N - Natural pH as determined by allowing the ash slurry to dissolve until no further pH change is noted.

TABLE 3. FLY ASH LEACHING RESULTS - PLANT 1873

Sample	Final pH	T°C	Grams Leached*	Major Species[†] Ca	K	Mg	Na	SO_4	Cl	CO_3	Si	Gypsum Relative Saturation[‡]
F-1	3.8	24	20	3.51	.461	.453	.201	11.5	.0355	ND	.251	.22
F-2	4.9	22	20	2.64	ND	.317	.201	9.48	.0569	ND	.107	.16
F-3	3.6	29	40	3.75	.403	.453	.184	17.7	.0249	ND	.338	.71
F-4	3.5	37	20	4.00	.454	.509	.184	12.9	.0355	.0120	.351	.25

Inorganic Priority Pollutants[‡,§]

Sample	Ag	Be	Cd	Cr	Cu	Ni	Zn	As	Sb	Hg	Tl
F-1	ND	.00050	.00050	.00256	.0184	.00604	.0194	.112	.00018	ND	.00058
F-2	.00002[#]	.00004	.00058	.00030[#]	.00434	.00598	.0151	.0440	ND	ND	.00076
F-3	.00008[#]	.00050	.00077	.00210	.0125	.0121	.0206	.0630	.00015	ND	.00037
F-4	.00068[#]	.00056	.00092	.00218	.0171	.00234	.0222	.107	.00040	.00008	.00080

[*] In 400 ml of DI water for 2 hours

[†] Concentrations expressed as mg/g of ash

[‡] Of filtrate liquor

[§] Pb, Se were undetected in all samples

[#] 50 percent or more of element present in leachate was due to the deionized sample blank

ND - Not detected

The fly ash leaching results are shown in Table 4 for Plant 4424. With an increase in pH, the amounts of Ca and Mg leached decreased and the amounts of other major species increased. With a decrease in solids level, the amount of all species except Cℓ increased. With an increase in temperature, all species except SO_4 increased.

The fly ash leaching results are shown in Table 5 for Plant 9677. With a decrease in pH, the levels of all species increased except SO_4 which decreased. With an increase in solids level, the Ca and Na levels dropped, but the K, Mg, and SO_4 levels increased. Higher temperatures increased the levels of all species except Mg, Na, and Cℓ, which stayed the same.

In summary, for the fly ash tests, an increase in temperature generally resulted in slightly higher levels of the major species leached. An increase in pH generally decreased the amount of alkaline species (Ca, Mg, K, Na) leached, and a decrease in pH generally increased the amount of alkaline species leached. Solids level did not appreciably affect the amount of species leached per gram of ash. None of the test conditions, however, significantly changed the results. Therefore, it should not be necessary to keep the fly ash heated in the sluicing studies or tightly control the pH or slurry solids.

The fly ash from Plant 4424 was the least reactive with respect to available calcium and sulfate levels with average values of .39 mg Ca/g ash and 2.75 mg SO_4/g ash. The fly ash from Plant 1873 was the most reactive with respect to sulfate with an average availability of 12.9 mg/g ash. The average calcium availability in the fly ash from Plant 1873 was 3.48 mg/g ash. The fly ash from Plant 9677 was the most reactive with respect to calcium with an average availability of 4.38 mg/g ash. The average sulfate availability in the fly ash from Plant 9677 was 6.08 mg/g ash.

TABLE 4. FLY ASH LEACHING RESULTS - PLANT 4424

Sample	Final pH	T°C	Grams Leached[*]	Major Species[†]								Gypsum Relative Saturation[‡]
				Ca	K	Mg	Na	SO_4	Cl	CO_3	Si	
F-5	3.6	21	20	.337	.140	.0450	.0433	2.63	.0640	ND	.0513	.01
F-6	4.6	21	20	.267	ND	.0346	.0982	2.71	.00995	.0480	.0207	.01
F-7	3.8	20	8	.583	.167	.0583	.0614	3.12	.0533	ND	.0532	.01
F-8	3.5	40	20	.375	.144	.0524	.0483	2.52	.0640	.0600	.0641	.01

Sample	Inorganic Priority Pollutants[†,§]										
	Ag	Be	Cd	Cr	Cu	Ni	Zn	Se	As	Sb	Hg
F-5	ND	.00012	.00026[#]	.00634	.00586	.00212	.00354	.00044	.00364	ND	ND
F-6	.00006[#]	.00008	.00008[#]	.00084[#]	.00350	.00306	.00386	.00239	.00112	ND	.00002
F-7	ND	.00010	ND	.00615	.00705	.00145[#]	.0264	.00695	.00915	ND	ND
F-8	ND	.00014	.00026[#]	.00332	.00814	.00274	.00530	.00262	.00290	.00002	ND

[*] In 400 ml of DI water for 2 hours

[†] Concentrations expressed as mg/g of ash

[‡] Of filtrate liquor

[§] Pb and Tl were undetected in all samples

[#] 50 percent or more of element present in the leachate was due to deionized sample blank

ND - Not detected

TABLE 5. FLY ASH LEACHING RESULTS - PLANT 9677

Sample	Final pH	T°C	Grams Leached*	Major Species[†]								Gypsum Relative Saturation[‡]
				Ca	K	Mg	Na	SO_4	Cl	CO_3	Si	
F-9	11.0	22	20	4.11	.197	.00696[#]	.113	4.82	.0142	.396	.0384	.13
F-10	10.0	22	20	5.26	.216	.0433	.163	3.96	ND	.852	.0193	.12
F-11	11.0	31	40	3.57	.206	.0258[#]	.104	10.1	.0142	.174	.0163	.52
F-12	10.6	39	20	4.58	.231	.00620[#]	.112	5.45	.0142	.240	.0533	.15

Sample	Inorganic Priority Pollutants[†,§]										
	Ag	Be	Cd	Cr	Cu	Ni	Zn	Se	As	Sb	Hg
F-9	.00032[#]	ND	.00018[#]	.00144	.00030[#]	.00014[#]	.00032	.00046	.00262	.00010	.00019
F-10	.00068[#]	.00002[#]	.00024[#]	.00218	.00044[#]	.00074[#]	.00060	ND	.00850	.00006	.00016
F-11	.00014[#]	ND	.00007[#]	.00129	.00011[#]	.00002[#]	.00035	.00053	.00132	.00002	.00017
F-12	.00030[#]	ND	.00016[#]	.00184	.00056[#]	.00050[#]	.00054	.00048	.00240	.00036	.00008

*In 400 ml of DI water for 2 hours

[†] Concentrations expressed as mg/g of ash

[‡] Of filtrate liquor

[§] Pb, Tl were undetected in all samples

[#] 50 percent or more of element present in leachate was due to the deionized sample blank

ND - Not detected

Bottom Ash Leaching Results

The bottom ash leaching results are shown in Table 6 for Plant 1873. Leaching at lower pH resulted in lesser amounts of Ca, Mg, and SO_4 leached and a greater amount of K. Crushing the bottom ash to a fine powder decreased the amount of all species leached, as did raising the suspended solids level. An increase in temperature from 32°C to 51°C resulted in lower amounts of species leached for all species except sodium.

The bottom ash leaching results are shown in Table 7 for Plant 4424. For this ash, leaching at lower pH resulted in lesser amounts of Ca, K, and SO_4, but a greater amount of sodium leached. Crushing the ash resulted in a decrease in the amount of all species leached except Na and SO_4, which increased substantially. An increase in the level of suspended solids resulted in lower levels of all major species leached, as did an increase in temperature from 33°C to 49°C. A decrease in solids content increased the level of all major species except calcium.

The bottom ash leaching results are shown in Table 8 for Plant 9677. Leaching at a lower pH resulted in an increase in the level of all major species except calcium. Crushing the ash raised the level of all species leached, and raising the solids level decreased the level of all species leached. Raising the temperature from 38°C to 49°C resulted in higher levels of all species except magnesium.

In summary, at lower pH levels, less Ca and less SO_4 were leached for the bottom ashes of two plants (4424, 1873). However, for Plant 9677, more SO_4 was leached at a lower pH, and Ca remained the same. For two plants (4424, 1873) crushing the bottom ash lowered the level of soluble species but for Plant 9677, crushing raised the level of soluble species. For all three ashes, raising the solids level decreased the amount of soluble species leached. For Plants 4424 and 1873, higher temperatures resulted in less

TABLE 6. BOTTOM ASH LEACHING RESULTS - PLANT 1873

Sample	Crushed	Final pH	T°C	Grams of Ash Leached*	Major Species†							
					Ca	Mg	Na	K	SO₄	Cl	CO₃	Si
B-1	No	6.0	32	2.0	.868	.0438‡	.339	.193	1.92	.709	1.20	.0884
B-2	No	6.0	22	2.0	.345	.0334‡	.337	.218	1.15	ND	0.720	.0958
B-3	Yes	5.7	19	2.0	.121	.0270‡	.267	.0786‡	0.960	ND	<0.120	.0319
B-4	No	5.9	33	4.0	.224	.0258‡	.208	.0656	0.864	.709	<0.060	.0329
B-5	No	5.6	51	2.0	.187	.0354‡	.341	.132	.960	.0355	0.120	.107

Sample	Inorganic Priority Pollutants†							
	Ag	Cd	Cr	Cu	Ni	Zn	As	Hg
B-1	ND	.00060‡	ND	.00080‡	.0190	.00260‡	.00660	.00002‡
B-2	.00180‡	.00100‡	.00220‡	.00020‡	.00520‡	.00460‡	.00340	.00578
B-3	.00020‡	ND	.00140‡	.00760‡	.0102	.0128	.00120	.00016
B-4	ND	ND	.00010‡	.00050‡	.00210‡	.00130‡	.00330	.00001‡
B-5	.00240‡	.00120‡	.00080‡	.00140‡	.00040‡	.00240‡	.00660	.00006

*Ash leached for 2 hours in 400 mls of DI water

†Concentrations in mg/g of Ash; Be, Pb, Sb, Se, Tl were not detected in any samples

‡DI blank contributed over 50 percent of value in leachate

ND - Not detected

TABLE 7. BOTTOM ASH LEACHING RESULTS - PLANT 4424

Sample	Crushed	Final pH	T°C	Grams of Ash Leached*	Major Species†							
					Ca	Mg	Na	K	SO_4	Cl	CO_3	Si
B-6	No	6.1	33	8.0	.140	.0160‡	.0663	.0663	.288	.0709	.150	.0347
B-7	No	5.0	22	8.0	.0764	.0166‡	.0928	.0552	.240	ND	<.030	.0227
B-8	Yes	6.2	27	8.0	.103	.0142‡	.115	.0564	.432	.0355	.180	.0239
B-9	No	6.2	32	20.0	.0608	.00688‡	.0247	.0317	.115	.0142	.0840	.0144
B-10	No	6.2	49	8.0	.0491	.00995‡	.0543	.0243‡	.144	.0355	.330	.0301
B-11	No	5.6	21	4.0	.104	.0252‡	.290	.142	.864	.106	.0600	.0649

Sample	Inorganic Priority Pollutants†								
	Ag	Cd	Cr	Cu	Ni	Zn	Se	As	Hg
B-6	.00025‡	.00025‡	.00035‡	.00028‡	.00140‡	.00350‡	ND	.00150	.00023
B-7	.00080‡	.00050‡	.00095‡	.00028‡	.00080‡	.00170	ND	.00030	.00075
B-8	.00050‡	.00030‡	.00070‡	.00026‡	.00090‡	.00165‡	ND	ND	.00017
B-9	ND	.00002‡	ND	.00070	ND	.00016‡	ND	.00126	.00020
B-10	ND	ND	ND	.00050‡	ND	.00060‡	ND	.00125	.00004
B-11	ND	ND	ND	.00140‡	ND	.00630	.00080	.00090	.00149

*Ash leached for 2 hours in 400 mls of DI water.

†Concentrations in mg/g of Ash; Be, Pb, Sb, Tl were not detected in any samples.

‡DI blank contributed over 50 percent of value in leachate.

ND - Not detected

TABLE 8. BOTTOM ASH LEACHING RESULTS - PLANT 9677

Sample	Crushed	Final pH	T°C	Grams of Ash Leached*	Major Species‡							
					Ca	Mg	Na	K	SO_4	Cl	CO_3	Si
B-12	No	7.4	28	4.0	1.20	.0208‡	.0868	.0497‡	0.672	ND	1.80	.0945
B-13	No	7.1	21	4.0	1.23	.0346‡	.0973	.0921	0.960	ND	1.32	.0709
B-14	Yes	6.65	19	4.0	1.30	.0322‡	.171	.118	1.92	.142	0.780	.0610
B-15	No	8.2	20	20.0	0.513	.00458‡	.0393	.0301	0.557	.0142	0.396	.0266
B-16	No	8.4	49	4.0	1.35	.0198‡	.0925	.0693	1.15	.0709	1.92	.238

Sample	Inorganic Priority Pollutants†								
	Ag	Be	Cd	Cr	Cu	Ni	Zn	As	Hg
B-12	.00170‡	.00010‡	.00100‡	.00180‡	.00100‡	.00200‡	.00220‡	.00100	.00038
B-13	.00330‡	.00010‡	.00140‡	.00370‡	.00230‡	.00440‡	.00230‡	.00170	.00063
B-14	.00240‡	.00010‡	.00110‡	.00250‡	.00170‡	.00330‡	.00300	.00110	.00085
B-15	.00008‡	ND	.00006‡	.00014‡	.00344‡	.00050‡	.00016‡	.00104	.00066
B-16	.00080‡	ND	.00060‡	.00120‡	.00070‡	.00110‡	.00130‡	.00660	.00369

*Ash leached for 2 hours in 400 mls of DI water.

†Concentrations in mg/g of Ash; Pb, Sb, Se, Tℓ were not detected in any samples.

‡DI blank contributed over 50 percent of value in leachate

ND - Not detected

amounts of species leached, but for Plant 9677 higher temperature resulted in more species leached. The reason for leaching less species from the ashes of Plants 1873 and 4424 when crushed is not known.

As with the fly ash, the bottom ash from Plant 4424 was the least reactive of all the bottom ashes with respect to calcium and sulfate. Plants 1873 and 9677 had about the same levels of soluble sulfate in the bottom ash and Plant 9677 had the highest level of soluble calcium.

In relation to the fly ash, the bottom ashes were less reactive with respect to calcium and sulfate. For Plant 1873, the ratio of available calcium in the fly ash to the available calcium in the bottom ash is about 10. For sulfate at Plant 1873, the ratio is about 11., based on average soluble amounts in Tables 1 and 4. For Plants 4424 and 9677, these ratios are smaller. For calcium, the ratios are 3.6 and 3.9, respectively, and for sulfate, the ratios are 6.6 and 5.8, respectively. The ratio of total dissolved species in the fly ash to bottom ash is 6.3 for Plant 1873, 4.3 for Plant 4424, and 3.0 for Plant 9677.

This relatively higher reactivity indicates that closed-loop sluicing of fly ash is more likely to create scaling and plugging problems than sluicing bottom ash. Additionally, dry bottom ash samples were available only at one site in sufficient quantity for test purposes. Also, using bottom ash in the vibratory hopper would have first required grinding which decreased the reactivity of two of the ashes. Consequently, only fly ash samples were tested in the bench scale unit.

PLANT SAMPLING RESULTS

The analytical results and description of each plant's sluicing system are given in Appendix A. However, it is useful to compare the leaching results to the plant samples here. Table 9 presents the plant results for the fly ash slurry stream in terms of milligrams of soluble species per gram of fly ash sluiced. This number was obtained by averaging the analysis

TABLE 9. AMOUNTS OF SPECIES LEACHED IN PLANT FLY ASH SLUICING OPERATIONS* (mg/g of Fly Ash)

PLANT	Ca	K	Mg	Na	SO_4	Cl	CO_3	Si
1873	20.8	2.16	1.35	1.72	86.5	-	2.18	.349
4424	.200	.140	.031	.034	3.19	-	-	.062
9677	4.48	.302	.074	.249	7.77	.052	-	.026

*Calculated from average results of plant samples. Raw sample data and plant descriptions are presented in Appendix A results for the fly ash slurry stream and the sluice water (service water, cooling water, or for two cases at Plant 9677, pond recycle water) given in Tables A-2, A-5, and A-8, respectively. The difference in these two numbers (mg/ℓ) was then divided by the average solids content in the slurry (g/ℓ) producing the leached amount (mg/g).

The results from Plants 4424 and 9677 agree very well with the leaching tests (Tables 4 and 5). The values from Plant 1873 are about 6-9 times greater than those seen in the leaching tests (Table 3). One possible explanation for this difference is the range of percent solids seen in the slurry stream (0.19-11.3 weight percent). If the values for the 11.3 weight percent solids sample are used, the resulting leached amounts (mg/g) are very close to those seen in Table 3.

BENCH SCALE RESULTS

A total of nine runs were made using the bench scale system, three with each fly ash. Table 10 lists the conditions under which each test was run. As stated earlier, the blowdown was specified as a percentage of the total flow of 0.3ℓpm from the mix tank. The mix tank had a residence time of two minutes for all of the runs except the last 30 hours of Run 9 when it was increased to five minutes. Air was bubbled through the pond during three of the runs to determine if CO_2 sorption/desorption between the pond and the atmosphere would affect the process chemistry; however, no significant effect was seen. The weight percent solids in the sluice water and blowdown rate were varied in order to correlate their effect on the pond water composition. Overall, the volume of ash and makeup water obtained from each plant site constrained both the number and length of tests performed.

Figure 2 shows the calcium and sulfate concentrations and the gypsum relative saturation in the pond liquid for Run 1 as a function of time. The other 8 runs are presented in this manner in Appendix B along with the remaining analytical results. Runs 1-3 (Plant 1873) all showed gypsum relative saturations above 1.3 in the pond at the end of each test. This indicates that the ash is highly reactive and could cause scaling problems unless the sluicing system either treated a portion of the recirculating water or ran in an open-loop mode.

Plant 4424 fly ash was much less reactive than Plant 1873. Even in the completely closed-loop mode, Run 4, the pond liquor was subsaturated with respect to gypsum (0.32) after 30 hours.

TABLE 10. TEST MATRIX FOR BENCH SCALE ASH SLUICE TESTS*

	Test	Blowdown	Slurry % Solids	Air in Pond	Duration, hr
1873	1	0	10	No	30
1873	2	10% (30 ml/min)	5	No	30
1873	3	20% (60 ml/min)	5	Yes	30
4424[†]	4	0	10	No	50
4424	5	10% (30 ml/min)	10	No	30
4424	6	20% (60 ml/min)	5	Yes	30
9677	7	20% (60 ml/min)	5	No	30
9677	8	10% (30 ml/min)	10	Yes	30
[‡]9677	9	0	10	No	60

*Samples taken every six hours for the pond recycle.
†Samples were taken more frequently at beginning of run.
‡Residence time of mix tank increased from two to five minutes during last 30 hours.

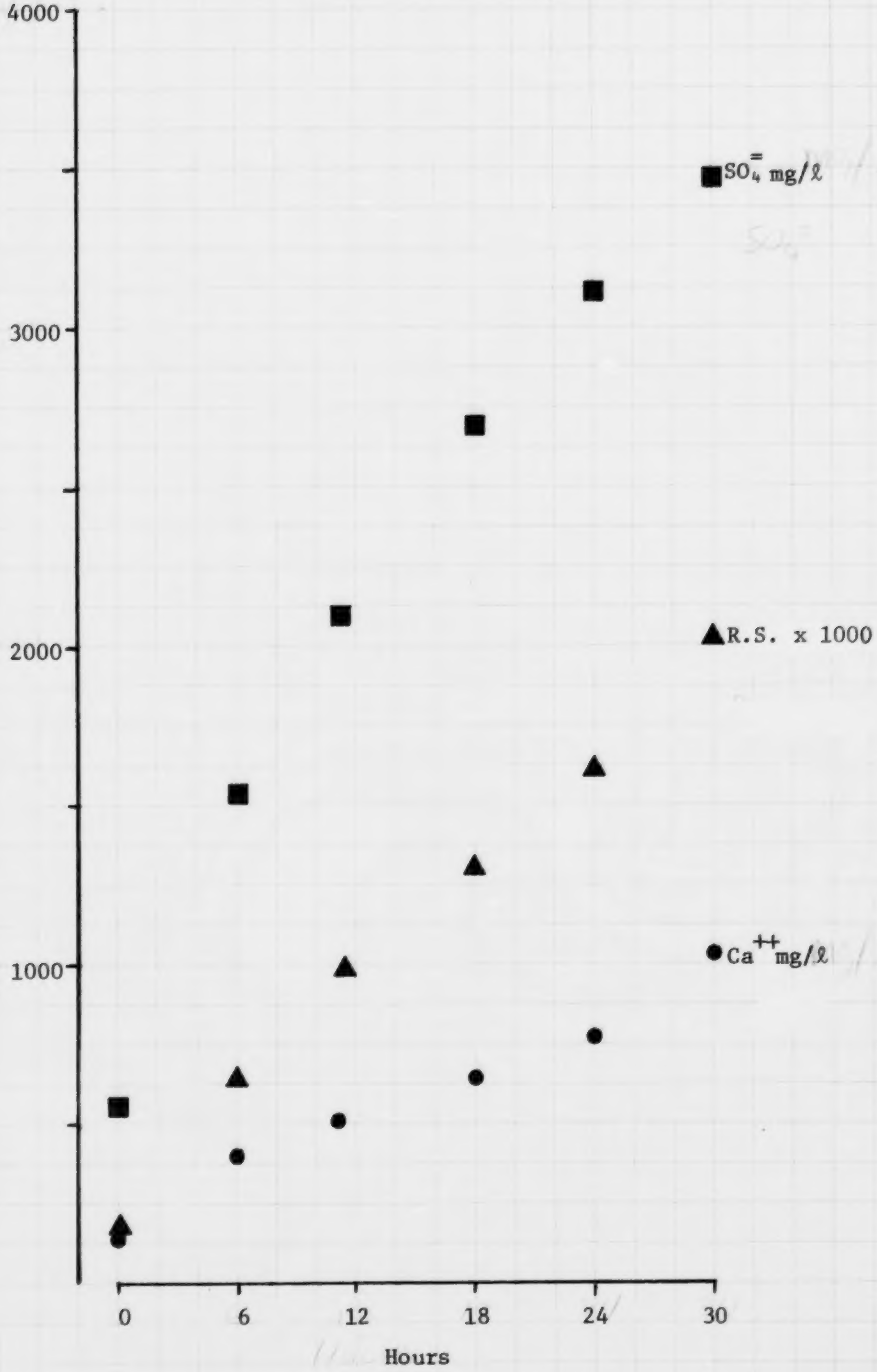


Figure 2. Plant 1873 Run 1.

Runs 7-9, using ash from Plant 9677, produced gypsum relative saturations between the first two series of tests. Run 7, at 20 percent blowdown and 5 percent solids was subsaturated after 30 hours. Run 8 was supersaturated with 10 percent blowdown and 10 percent solids in the mix tank. Run 9, no blowdown, was supersaturated and produced some visible scale on test coupons in the system. This scale was analyzed and determined to be calcium sulfate (gypsum).

Unfortunately, none of the tests were run long enough to reach steady-state conditions. This was due to two factors. First, the residence time of the liquid in the system varied from 25 to 105 hours, depending on the blowdown rate and the settled ash density. Consequently, to reach a steady-state condition during closed-loop operation would have required about 300 hours of testing. The amount of material available (fly ash and makeup water) was insufficient for three tests of each ash for a long period. It was felt that the three different tests of each ash were more important than a single test of each. However, stream compositions at steady-state conditions were estimated from the data collected during these tests. The next section discusses the treatment of the bench scale data required to arrive at steady-state concentrations.

DETERMINATION OF STEADY-STATE CONCENTRATIONS AND ASH REACTIVITY

Normally, for constant input conditions, the time required to reach steady state is a function of the system residence time. There are two residence times which are important in the bench system. The first is the liquid residence time in the pond. This value was on the order of 6.3 hours (114ℓ/18ℓph). The second, the overall liquid residence time in the system, is related to the blowdown rate and the occluded water in the settled solids. Table 11 presents the overall liquid residence time for each of the test runs. As can be seen, the runs with zero blowdown had the longest residence times. Variations in times are due to different percent solids concentrations in the pond and the mix tank.

TABLE 11. SYSTEM RESIDENCE TIMES

Plant	Run	Residence time (hrs)	Percent blowdown	Percent solids (mix tank)	Percent solids (ash pond)
1873	1	68	0	10	54
	2	33	10	5	54
	3	25	20	5	54
4424	4	73	0	10	53
	5	30	10	10	53
	6	25	20	5	53
9677	7	27	20	5	65
	8	39	10	10	65
	9	105	0	10	65

Since the overall liquid residence time is much larger than the liquid residence time in the pond, the system can be modeled by a first order differential equation. This assumption implies that the pond composition is not changing rapidly with the time. In other words, the liquid exiting the mixing tank has about the same composition as the liquid leaving the system at that same instant. The greater the difference in residence times, the closer the bench unit models a first order system and approximates the assumption.

For a first order system, a differential mass balance can be made such as Equation 1:

$$QC_{IN} - QC_{OUT} = \frac{d(VC)}{dt} \qquad (1)$$

where Q is the flow rate, C is the concentration and V is the system volume. For a constant volume system, $\frac{dV}{dt} = 0$; therefore, the residence time T is equal to the volume divided by the flow rate. A first order equation also assumes that C_{IN} is constant. Therefore, upon integration, Equation 2 can be used to determine steady-state concentrations:

$$C(t) = (C_{ss}-C_o)[1-\exp(-t/T)] + C_o \qquad (2)$$

where C is the concentration of a soluble species at time t, C_{ss} is the steady-state value, C_o is the concentration at t = o, t is the sample time and T is the system residence time. By plotting $C-C_o$ versus $1-\exp(-t/T)$, a line with the slope of $C_{ss}-C_o$ is generated. If the data is accurately modeled by this equation, the intercept ($C-C_o$, at t=o) will be zero. Figure 3 is a plot of $C-C_o$ versus $1-\exp(-t/T)$ for the calcium concentration during Run 1. As can be seen, the intercept is near zero. The slope of the line ($C_{ss}-C_o$) is 2275. The initial calcium concentration was 134 mg/ℓ. Therefore, the steady-state value predicted by this model is 2409 mg/ℓ. In a similar manner, values for all of the species which can be input to the ionic equilibrium program were calculated. The analytical data used in these calculations are presented

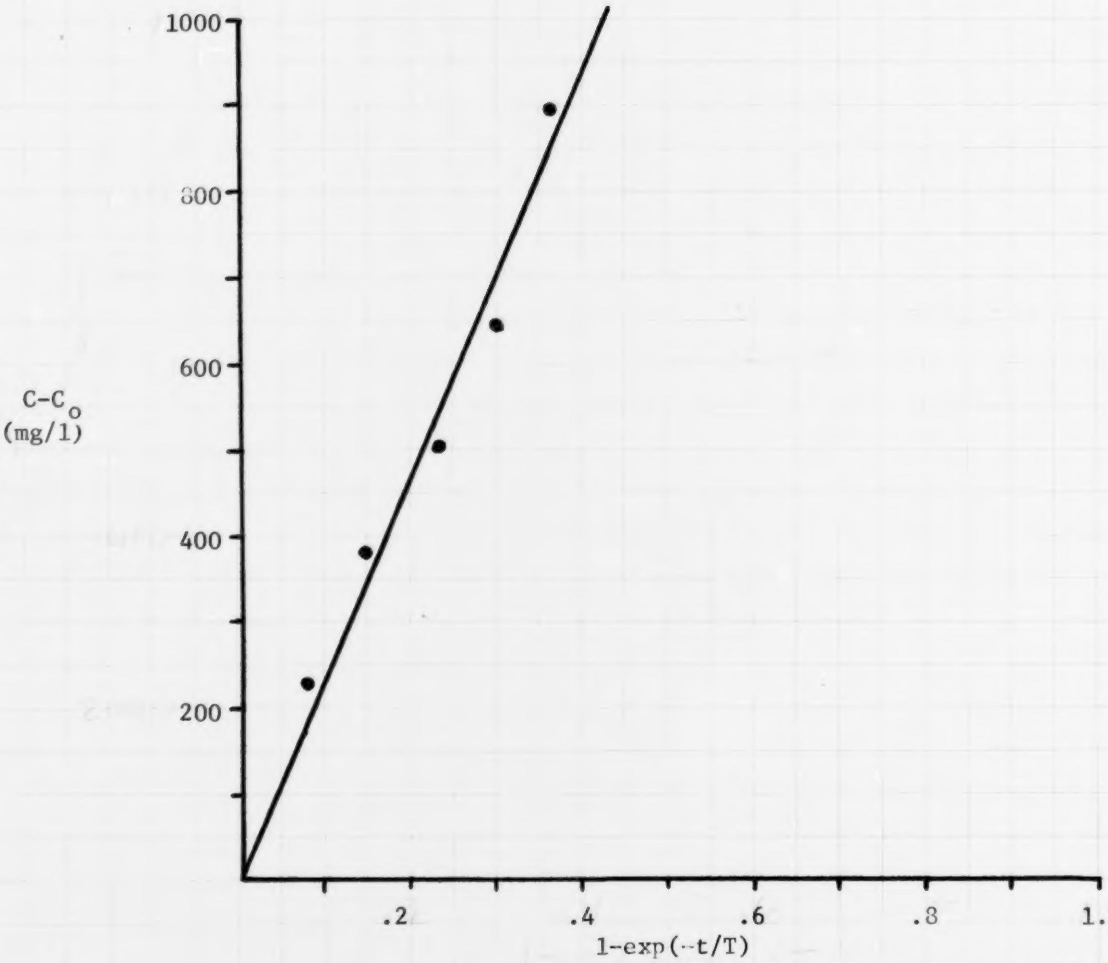


Figure 3. Graphical determination of steady state calcium concentration - Run 1.

in Appendix B. These calculated steady-state concentrations and the predicted gypsum relative saturations are presented in Table 12. The numbers under the concentration values are the correlation coefficients calculated from the linear least squares curve fit. Values close to ±1 indicate a very good fit. Values between ±.5 generally appear as a random pattern of data.

As can be seen, five of the nine runs have gypsum relative saturations above equilibrium and the 1.3 value at which scaling can be a problem. It is not likely that these high concentrations would be reached at steady state because precipitation of calcium sulfate would occur. It is probable that the leaching rate from the ash would stay constant, and the net increase in calcium and sulfate would only rise to slightly supersaturated conditions. Assuming the leaching rate is constant, it is possible to calculate a relationship between the amount of ash sluiced and the percent of the recycle water which must be treated to prevent scaling from occurring in a closed-loop system.

In order to determine this relationship, two parameters are needed. They are the equilibrated chemical composition of the sluice water and the fraction of soluble species in the ash which dissolve.

The equilibrated compositions were obtained by adjusting the steady-state concentrations in Table 12 until a gypsum relative saturation of near 1.0 was obtained. The soluble species (Mg, K, Na, Cl, Si) were adjusted by the square root of the relative saturation at steady state. The gypsum saturation is proportional to the product of the calcium and sulfate concentrations and individual ion concentrations (neglecting precipitation and sorption/desorption) are directly proportional to the amount of blowdown (including solids occlusion). Therefore, the blowdown change (and soluble ion concentration change) to adjust the saturation level to 1.0, varies with the square root of the relative saturation. For Plant 1873, the potassium value used was 24 mg/ℓ. This was obtained by dividing the

TABLE 12.   STEADY-STATE LIQUID CONCENTRATIONS*

Run	pH	Ca	K	Mg	Na	Si	SO$_4$	Cl	CO$_3$	Gypsum Relative Saturation
1	3.0	2409 .98	236 .97	143 .99	119 .97	205 .99	7600 .99	15[†]	27[†]	5.22
2	3.1	1058 -.60	32 -.91	44 -.99	17 -.99	36 -.98	2390 -.98	0[†]	25[†]	1.75
3	3.5	1010 -.78	46 -.99	54 -.99	26 -.99	41 -.96	2170 -.98	5[†]	50[†]	1.60
4	3.2	224 .99	121 .99	40 .99	-	23 .97	1960 .99	42 .83	-	.48
5	3.5	148 -.96	74 -.94	25 -.74	-	13 -.99	1230 -.76	33 -.15	-	.28
6	3.5	95 -.99	35 -.99	18 -.99	-	9 -.97	545 -.99	8 -.89	-	.13
7	9.3	440 .98	50 .97	10[†]	30 .75	1[†]	945 .99	4[†]	30[†]	.58
8	8.8	1560 .92	153 .92	7[†]	80 .85	2[†]	2370 .99	5[†]	40[†]	2.14
9	7.4	2435 .82	289 .95	59 .94	167 .96	7[†]	3800 .92	2[†]	-	3.53

*Top value is concentration in mg/ℓ, bottom value is correlation coefficient of data fit.

[†] Based on average of values taken, no trend observed.

steady-state potassium value in Run 2 by the square root of the relative saturation, 1.75. The calcium and sulfate values were initially adjusted in this manner also. They were then readjusted until the relative saturation approached 1.0. Table 13 gives the composition of the three equilibrated streams and the computer calculated gypsum relative saturations.

The fraction of soluble species leached from the ash was calculated using the steady-state values in Table 12, the liquid flow rates, the ash addition rate and the results of the leaching tests. Input streams were the makeup water and ash, output streams were the occluded water and the blowdown. By performing a material balance, the amount of a species obtained from the ash can be calculated. Dividing this value by the average of the ash analysis given in Tables 3, 4, and 5 gives the fraction leached. Table 14 presents the results of this exercise. The fraction leached for each ash in the following calculations was assumed to be the average of the two highest fractions in Table 14.

Thus, all of the necessary information is now available to develop the relationship between the amount of ash sluiced and the amount of sluice water to be discharged (to prevent scaling). As an example, the relationship for Plant 1873 is developed.

Several assumptions are necessary in order to make these calculations. They are:

1) The amount of a species being leached is only dependent on the percent solids of ash. On an mg/g basis, this is a constant value.

2) The activity product of calcium sulfate is proportional to the product of the calcium and sulfate concentrations.

TABLE 13. EQUILIBRATED SLUICE STREAM COMPOSITIONS (mg/1)

Plant	pH	Ca	Mg	Na	K	Cl	CO_3	SO_4	SiO_2	Gypsum Relative Saturation
1873	3.5	810.	33.	13.	24.	5.	50.	1290.	58.	1.01
4424	3.5	410.	58.	-	175.	61.	-	3140.	71.	.95
9677	9.0	770.	13.	39.	66.	5.	35.	1370.	-	1.04

TABLE 14. FRACTIONAL LEACHED SPECIES IN BENCH SCALE TESTS*

Plant	Run	Ca	Mg	Na	K	Cl	Si	SO_4
1873	1	.64	.30	.54	.50	.24	.72	.63
	2	.94	.35	.19	.25	-	.47	.75
	3	1.00	.56	.46	.46	-	.70	.90
4424	4	.41	.54	.29	.67	.71	.38	.59
	5	.60	.69	.52	.97	1.00	.47	.89
	6	.77	.90	.62	1.00	.71	.70	.92
9677	7	.45	.95	1.00	1.00	-	-	.90
	8	.54	.17	.97	1.00	-	-	.78
	9	.32	.95	.77	.78	-	.02	.46

*mg leached/mg present (as determined by leaching studies)

For Plant 1873, the maximum concentrations of Ca and SO_4 which can be present in the pond are 810 and 1290 mg/ℓ (.0203M, .0134M), respectively. Therefore, the maximum activity product allowed in the pond water is 2.72×10^{-4}. The amount of calcium and sulfate leached from the ash is dependent on the ash composition, the fraction dissolving, and the total amount being sluiced. The first two parameters are obtained from Tables 3 and 14. The values presented are averages of four numbers from Table 3 and the two highest values on Table 14.

$$\text{Ca from ash} = 3.47 \left(\frac{\text{mg Ca}}{\text{g Ash}}\right) \times \frac{1}{40080} \left(\frac{\text{mol}}{\text{mg}}\right) \times .97 \left(\frac{\text{mg Ca leached}}{\text{mg Ca available}}\right) \qquad (3)$$

$$= 8.4 \times 10^{-5} \text{ mol Ca/g of Ash}$$

$$SO_4 \text{ from ash} = 12.9 \times \frac{1}{96060} \times .83 \qquad (4)$$

$$= 1.1 \times 10^{-4} \text{mol } SO_4\text{/g of Ash}$$

In a constant liquid volume system, the makeup water rate will equal the blowdown rate plus the amount of water occluded with the settled solids. Consequently, the makeup water quality will have a large effect on the amount of ash which can be sluiced. For river water makeup, the quality is usually good as evidenced by the plant sample results in Appendix A. Therefore, in the bench scale runs, the amount of Ca and SO_4 added by the makeup water was negligible. On a one-liter basis then, the maximum weight of sluiced ash can be calculated by Equation 5:

$$ACaSO_4 = \left(ACa\right) \left(ASO_4\right) \qquad (5)$$

$$2.72\times10^{-4} = 8.4\times10^{-5}\left(Xg\right) \times 1.1 \times 10^{-4}\left(Xg\right)$$

$$X = \sqrt{2.94\times10^{4}} \text{ g}$$

$$= 172 \text{ grams of ash/liter of makeup water}$$

where $ACaSO_4$ is the maximum calcium sulfate activity product and ACa and ASO_4 are the activities of calcium and sulfate, respectively.

Now the occluded water rate is simply a function of the total ash flow and the final settled weight percent solids in the pond. Therefore, the blowdown (BD) can be expressed as the makeup rate (MW) minus the occluded water.

$$BD(\ell pm) = MW(\ell pm) - \left[\frac{46gMW}{54g\ Ash} \times \frac{172g\ Ash}{1000\ gMW} \times MW(\ell pm)\right] \quad (6)$$

$$= .853\ MW(\ell pm)$$

The fractional blowdown (FBD), as defined earlier, is the blowdown divided by the makeup water and the recirculating pond water rate (R).

$$FBD = \frac{BD}{MW+R} = \frac{.853\ MW}{MW+R} \quad (7)$$

The weight percent solids in the slurry stream is simply the ash flow rate (X) divided by the makeup and recycle flows, (assuming a liquid density of 1.0 g/mℓ).

$$Y\ (\text{weight fraction}) = \frac{X(g/min)}{MW+R(\ell pm)} \times \frac{1\ell}{1000g} \quad (8)$$

The maximum ash rate has already been determined, 172 g/ℓ; therefore, combining Equations 6 and 7 produces the desired relationship.

$$FBD = \frac{.853\ MW}{\frac{172}{Y(1000)}} = 4.96Y \quad (9)$$

In other words, if Plant 1873 sluices a 10 percent slurry, 50 percent of the recirculating and makeup water must be either discharged or treated to the makeup water quality with respect to calcium and sulfate in order to prevent gypsum supersaturation, whereas for a 5 percent slurry, 25 percent blowdown is required.

The same calculations for Plant 9677 produces Equation 10:

$$FBD = 2.68Y \qquad (10)$$

For this plant, a 10% slurry requires about 27% blowdown as compared to 50% for Plant 1873. The data for Plant 4424 indicate that it would be possible to operate this sluicing system in a closed-loop mode without reaching gypsum supersaturation. The amount of calcium and sulfate leached from the ash is low enough that the occluded water rate can keep the concentrations below the equilibrium values. Consequently, no blowdown or sidestream treatment would be needed.

SECTION 4

COMPARISON OF BENCH SCALE RESULTS TO THE COMPUTER MODEL PREDICTIONS

The computer model developed under EPA Contract 68-01-5163 was used to check the results obtained from the bench scale data and calculations. The model has eight basic options with respect to the treatment of the sluicing water. These options are presented in Table 15.

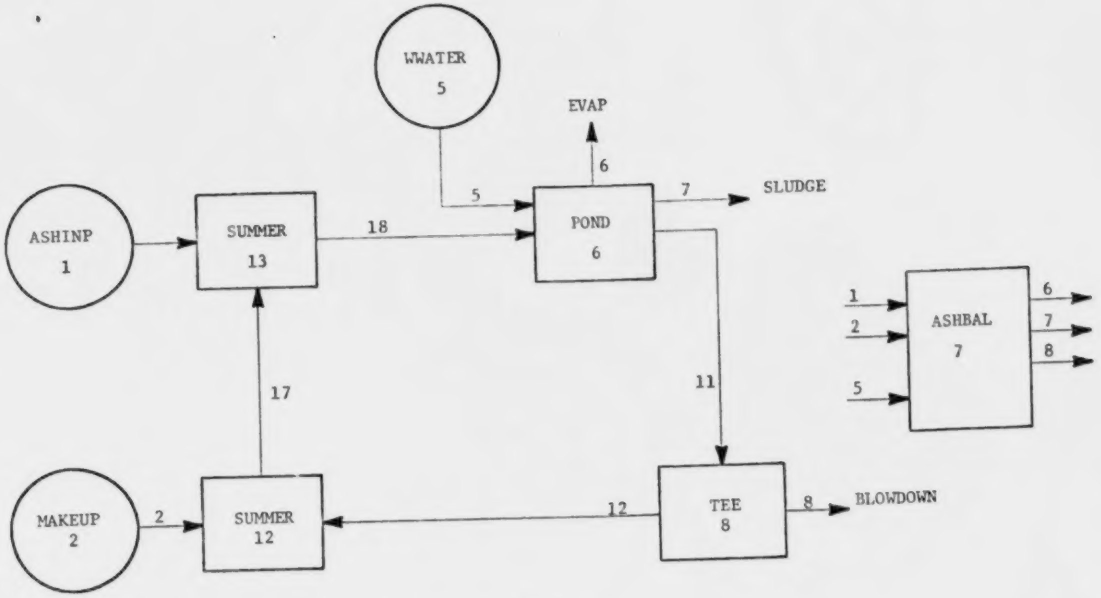
TABLE 15. SLUICE WATER TREATMENT OPTIONS

1 - No treatment
2 - Acid/caustic addition
3 - Sidestream softening
4 - Reactor/hold tank for precipitation
5 - Acid/caustic addition with sidestream softening
6 - Acid/caustic addition with reactor/hold tank
7 - Sidestream softening with reactor/hold tank
8 - Acid/caustic addition with sidestream softening and reactor/hold tank

In order to verify the bench scale results, option 1, no treatment, was specified. Figure 4 is a block diagram of the calculations performed by the program. ASHBAL is an overall material balance subroutine for the system.

The following data is required as input to the program for the various subroutines:

ASHINP - temperature, mass rate, and weight fraction of soluble species (Ca, Mg, Na, Ki, Cl, SO_4, SiO_2) and inerts in the ash


WWATER
5
EVAP
6
ASHINP
1
SUMMER
13
18
5
POND
6
7
SLUDGE
ASHBAL
7
1
2
5
6
7
8
17
11
MAKEUP
2
2
SUMMER
12
12
TEE
8
8
BLOWDOWN

ORDER OF CALCULATIONS: 1, 2, 5, 7 (8, 12, 13, 6, 7)*

*Iterative calculational sequence

Figure 4. Option 1 - No Treatment of Sluice Water

MAKEUP - temperature, pH, and composition of makeup water

WWATER - wastewater flow and composition (if other waste streams are added to the pond)

POND - evaporation rate, percent solids in sludge, surface area, depth of the pond

ASHBAL - blowdown rate, percent solids in ash slurry

The output from the program provides the pond water composition including the gypsum relative saturation and the required makeup water rate, when using Option 1. If the gypsum relative saturation is too high or low, the user must select a new blowdown rate and/or ash loading.

Using the predictive equations developed in Section 3, the blowdown rate was expressed as a function of the percent solids. These values were input to the model. The results are presented in Table 16. As can be seen, the relative saturation predicted for the pond liquor using the model is very close to 1.0, the value used in the bench scale correlations. A second run of Plant 1873 at a higher percentage blowdown than necessary indicates a fairly large dependence of relative saturation on the blowdown rate. As found earlier, the model verifies the feasibility of sluicing ash from Plant 4424 in a closed-loop mode. A small blowdown rate was necessary for the model to prevent division by zero in the program.

TABLE 16. COMPUTER AND BENCH SCALE PREDICTED RESULTS

Plant	Percent solids in sluice stream	Percent blowdown predicted by data to maintain gypsum saturation at 1.0	Percent blowdown input to model	Model* predicted relative saturation
1873	5.0	24.8	25	1.01
1873	5.0	24.8	35.4	.70
4424	10.0	None	.004†	.57
9677	10.0	26.8	28	1.04

*A relative saturation of 1.0 or less indicates that scaling is not anticipated to occur in the sluice system.

†A small value was required to prevent division by zero in the model.

APPENDIX E.1

Prior to the bench scale sluicing and leaching tests, site visits were made to each of the three utilities who particpated in this study. Samples were taken at each plant around their ash sluicing systems. This appendix describes the sluicing systems at each plant and presents the analytical results of the various process streams.

PLANT 1873

Plant 1873 is a 98 MW electric power generating station, consisting of two units of 49 MW each. Both units burn bituminous coal from Alabama. An analysis of a coal sample taken during a visit to the plant on 25-27 October 1979 is presented in Table E.1-1. About 10 percent of the ash generated from coal combustion at Plant 1873 is collected as bottom ash and the remaining 90 percent is fly ash.

Plant 1873 uses wet sluicing and ponding for disposal of both fly ash and bottom ash from both units. Both bottom ash and fly ash are disposed of in a common pond. All other waste streams from the plant are also sent to the ash pond. A block diagram of the ash handling system is shown in Figure E.1-1.

Plant 1873 uses service water to sluice both fly ash and bottom ash. The service water source is a nearby river. The incoming water is not treated before use in the system.

Figure E.1-1 also shows the points in the plant water system which were sampled during a visit to the plant on 25-27 October 1979. The analytical results from the samples are presented in Tables E.1-2 and E.1-3.

Table A-2 shows the major species concentrations (Ca, Mg, Na, K, Si, SO_4 Cl, and total carbonate) as well as the measured pH, temperature and suspended solids content for slurry streams. Table A-3 shows the inorganic priority pollutants which were measured in the samples. These analyses for trace species were performed on composites of the individual samples taken at each sample point during the visit. The composites were generated by mixing equal portions of each individual sample.

Since the 10/25 p.m. sample for the fly ash slurry was so dramatically different from the other fly ash slurry analyses, and a high arsenic level was detected (34.8 mg/l) in the composite, analyses for arsenic in each individual sample were also made. For the 10/25 p.m. sample, the arsenic level was below the detection limit, .003 mg/l. The results of analysis of the other three fly ash slurry liquor samples for arsenic were 37.4, 50.5, and 28.7 mg/l, respectively.

The total ash production rate for plant 1873 at full load is about 3860 kg/hr, which results in about 3450 kg/hr fly ash and 410 kg/hr bottom ash. The fly ash sluice water pump capacity is about 5700 ℓpm, which results in about 1.0 percent solids slurry at design conditions. However, since fly ash is sluiced intermittently until a hopper is empty, the instantaneous slurry solids content varies considerably, as illustrated by the sample analyses in Table A-2.

The bottom ash sluice water pump capacity is about 380 ℓpm, which results in about a .2 percent solids slurry. The actual plant samples, taken when sluicing first started, had solids levels of 0.3-0.5 percent.

PLANT 4424

Plant 4424 is a 950 MW electric power generating station that burns Eastern Kentucky bituminous coal. An analysis of a coal sample taken during a plant visit on 22-24 October 1979 is presented in Table A-4.

Plant 4424 uses wet, once-through sluicing for both fly ash and bottom ash. A block diagram of the ash disposal system at Plant 4424 is shown in Figure A-2. Both bottom ash and fly ash are sluiced with water from the inlet of the main condensers (once-through cooling is used at Plant 4424). Bottom ash is collected at the bottom of the boilers and sluiced to Ash Pond No. 1, as shown in Figure A-2.

Fly ash is collected with electrostatic precipitators and most of it is sluiced to Ash Pond No. 2. Plant 4424 has two sets of precipitators. The old precipitators are not energized, but collect the heavier particles of fly ash. This portion of the fly ash is sluiced to Ash Pond No. 1. The newer precipitators are in series with the old precipitators and the ash collected in them is sluiced to Ash Pond No. 2. Other streams which enter Ash Pond No. 1 are the drain from the power house bilge sump, floor drains, and effluent from the chemical treatment pond. Other streams which enter Ash Pond No. 2 include the liquid overflow from Ash Pond No. 1 and drainage from the coal pile runoff pond.

Also shown in Figure A-2 are the points in the ash system which were sampled during the plant visit on 22-24 October 1979. The analytical results of those samples are presented in Tables A-4 and A-5. Table A-4 shows the major species concentrations (Ca, Mg, Na, K, Si, SO_4, Cl, and total carbonate) as well as the measured pH, temperature, and suspended solids content for slurry streams. Table A-6 shows the inorganic priority pollutants which were measured. These analyses for trace species were performed on composites of the individual samples taken at each sample point during the visit. The composites were generated by mixing together equal portions of each individual sample.

PLANT 9677

Plant 9677 is a 3160 MW electric power generating station, consisting of four units. Units 1 and 2 are 700 MW each and Units 3 and 4 are 880 MW each. All units burn bituminous coal from Eastern Kentucky in Bureau of Mines Districts 8 and 9. An analysis of a coal sample taken during a visit to the plant on 10/29 - 10/31/79 is presented in Table A-7. The boilers are tangential-fired and result in about 67 percent of the total ash being fly ash and 33 percent as bottom ash.

Plant 9677 uses wet sluicing and ponding for disposal of both fly ash and bottom ash from all four units. A small portion of fly ash is collected dry and sold locally. Both bottom and fly ash are disposed of in a common pond. Other streams which also enter the ash pond include roof and floor drains (about 5700 ℓpm), sewage treatment plant and water treatment wastes (about 250 ℓpm). A conceptual diagram of the pond system is shown in Figure A-3.

Plant 9677 has the option of using cooling tower blowdown or ash pond water to sluice bottom and fly ash, as shown in Figure A-3. Plant makeup water is taken from a nearby river and used for cooling tower makeup. The cooling towers generally operate at 2-3 cycles of concentration. The portion of cooling tower blowdown not used to sluice ash is mixed with the ash pond overflow (after pH adjustment) before being discharged.

Figure A-3 shows the eight points in the ash handling system at Plant 9677 which were sampled during the visit on 29-31 October 1979. The analytical results from those samples are presented in Tables A-8 and A-9. Table A-8 shows the major species concentrations (Ca, Mg, Na, K, Si, SO_4, Cl, and total carbonate) as well as the measured pH, temperature, and suspended solids content for slurry streams. Table A-9 shows the inorganic priority pollutants which were analyzed for in the samples. These analyses for trace species were performed on composites of the individual samples taken at each sample point during the visit. The composites were generated by mixing together equal portions of each individual sample. The three miscellaneous plant drain streams shown in the tables were taken as they entered the ash pond and represent floor and roof drains from various parts of the plant. The fly ash and bottom ash slurries were sampled from Unit 4.

The total ash production at Plant 9677 under full load conditions is about 72,000 kg/hr fly ash and 35,500 kg/hr bottom ash for all four units (based on 10 percent ash in the coal). The average daily sluice rate for fly ash is 50,000 ℓpm, which corresponds to about 4 percent solids in the fly ash slurry. Fly ash is typically sluiced for about 2-1/2 hours every 4 hours. The average daily sluice rate for bottom ash is 44,000 ℓpm which corresponds to about 2.7 percent solids in the bottom ash slurry. The instantaneous level of solids in the ash slurries can vary significantly, as shown by the sample analyses in Table A-8. During a sluicing operation, the solids content of the slurry generally starts at a high value and decreases as ash is removed from a particular hopper or set of hoppers.

At Plant 9677, the bottom ash is conveyed from the boilers to the ash pond through 25cm diameter pipes. One pipe is used for each boiler. The distance from the boilers to the ash pond entry point varies from 490 meters for Unit 1 to 690 meters for Unit 4. The fly ash from Units 1 and 2 is collected by electrostatic precipitators and slurried to the ash pond in 25cm diameter pipes (one per boiler). The fly ash from Units 3 and 4 is also collected by electrostatic precipitators and sluiced in 25cm diameter pipes to the ash pond. Two pipes for each of Units 3 and 4 are used to sluice fly ash.

The plant floor and roof drains are collected and enter the ash pond at the same point as the fly ash and bottom ash. The ash pond has a surface area of about 1.1 million square meters with an average depth of 14 meters. As shown in Figure A-3, the pond overflow pH is adjusted with sulfuric acid prior to mixing with cooling tower blowdown and final discharge.

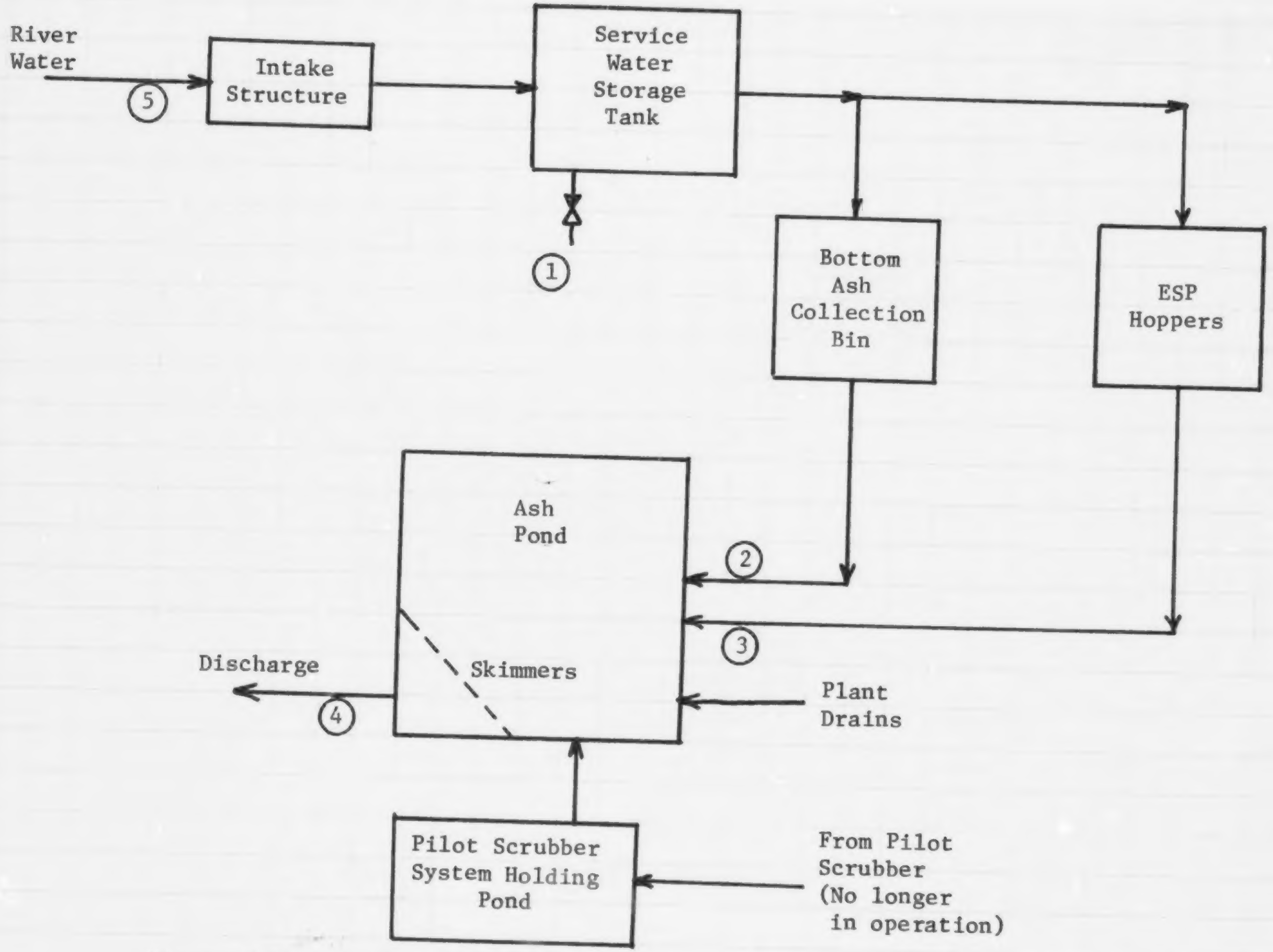

River Water
⑤
Intake Structure
Service Water Storage Tank
①
Bottom Ash Collection Bin
ESP Hoppers
Ash Pond
②
③
Skimmers
Discharge
④
Plant Drains
Pilot Scrubber System Holding Pond
From Pilot Scrubber (No longer in operation)

Figure E-1.1. Plant 1873 Ash Handling Block Diagram and Sample Points

TABLE E-1.1. COAL AND ASH ANALYSIS FOR PLANT 1873

Coal Ultimate Analysis

Species	Wt %
Moisture	5.31
Carbon	68.43
Hydrogen	4.70
Nitrogen	1.57
Chlorine	0.08
Sulfur	3.33
Ash	11.32
Oxygen (diff)	5.26
	100.00

Heating Value = 12,330 Btu/lb

Ash Mineral Analysis

Species	Wt %
SiO_2	38.87
Al_2O_3	17.23
TiO_2	0.80
Fe_2O_3	35.25
MgO	0.97
CaO	1.33
K_2O	2.12
Na_2O	0.71
SrO	0.00
BaO	0.09
SO_3	0.57

TABLE E-1.2. SAMPLE ANALYSES FOR PLANT 1873 (MAJOR SPECIES, mg/ℓ)*

Sample Point	Date	Ca	Mg	Na	K	Si	SO_4	Cℓ	Total CO_3	pH	T,°F	Wt % Solids	Gypsum Relative Saturation
Service Water	10/25 p.m.	10.9	1.3	6.3	1.8	1.3	12.5†	5.7†	42.6	8.1	70	-	.001†
	10/26 a.m.	11.7	1.4	6.2	1.6	1.6			37.2	7.2	68	-	
	10/26 p.m.	11.6	1.4	6.2	1.6	1.4			45.6	7.3	81	-	
	10/27 a.m.	12.1	1.5	6.3	1.5	1.3			46.2	7.5	59	-	
Bottom Ash Slurry	10/26 a.m.	57.3	10.8	10.9	1.7	3.7	99.8	16.7	94.8	6.4	74	0.53	.025
	10/27 a.m.	25.3	4.7	7.6	3.8	2.6	42.2	6.4	67.8	7.2	72	0.32	.006
Fly Ash Slurry	10/25 p.m.	13.2	1.7	6.4	2.2	1.6	72.0	5.3	104	4.5	82	2.06	.006
	10/26 a.m.	208	14.3	25.3	42.3	21.6	1210	5.3	43.8	2.6	80	0.19	.349
	10/26 p.m.	268	17.3	24.1	37.4	25.0	1334	5.3	57.0	2.4	86	11.34	.427
	10/27 a.m.	371	25.2	11.7	9.1	12.0	774	5.0	52.2	3.3	61	2.08	.448
Pond Discharge	10/25 p.m.	80.5	9.6	18.8	8.3	6.4	202†	21.3†	27.6	7.0	67	-	.059
	10/26 a.m.	87.6	9.4	12.5	8.6	7.0			30.6	7.1	57	-	.065
	10/26 p.m.	80.6	9.4	18.3	8.9	6.6			21.0	7.6	68	-	.059
	10/27 a.m.	78.0	9.2	14.8	7.2	6.3			28.2	6.7	58	-	.059
Plant Intake	10/26 p.m.	14.4	1.7	6.6	1.7	1.9	9.6	4.6	42.6	7.9	71	-	.001

*All analyses except Cℓ, SO_4, total CO_3 performed by inductively coupled argon plasma emission spectroscopy (ICAPES) Cℓ, SO_4 analyses performed by ion chromatography. Total CO_3 analyses performed by non-dispersive IR.

†Analyses performed on composite samples.

TABLE E-1.3. COMPOSITE SAMPLE ANALYSES FOR PLANT 1873 (13 INORGANIC PRIORITY POLLUTANTS, mg/ℓ)*

Sample Point	Ag	Be	Cd	Cr	Cu	Ni	Zn	As	Se	Sb	Hg	Pb	Tl
Service Water	<.002	<.001	<.001	<.002	0.005	<.030	<0.020	0.014	<.005	<.005	<.001	.009	<.002
Bottom Ash Slurry	<.002	<.001	<.001	<.002	0.010	<.030	<0.020	0.019	<.005	<.005	<.001	<.002	<.002
Fly Ash Slurry	<.002	.028	.050	.320	2.11	.190	1.19	34.8	.016	.059	<.001	.018	.184
Pond Discharge	<.002	<.001	.002	<.002	0.061	.060	0.049	1.44	<.005	<.005	<.001	<.002	<.002
Plant Intake	<.002	<.001	<.001	<.002	0.003	<.030	<0.020	0.026	<.005	<.005	<.001	.003	<.002

*All analyses performed by atomic absorption

TABLE L-1.4. COAL AND ASH ANALYSIS FOR PLANT 4424

Coal Ultimate Analysis

Species	Wt %
Moisture	8.19
Carbon	62.95
Hydrogen	4.19
Nitrogen	1.29
Chlorine	0.05
Sulfur	1.06
Ash	14.57
Oxygen (diff)	7.70
	100.00

Heating Value = 11,160 Btu/lb

Ash Mineral Analysis

Species	Wt %
SiO_2	56.85
Al_2O_3	28.27
TiO_2	1.57
Fe_2O_3	4.42
MgO	0.96
CaO	0.66
K_2O	2.89
Na_2O	0.15
SrO	0.05
BaO	0.05
SO_3	0.60

TABLE E-1.5. SAMPLE ANALYSES FOR PLANT 4424 (MAJOR SPECIES, mg/ℓ)*

Sample Point	Date	Ca	Mg	Na	K	Si	SO_4	Cℓ	Total CO_3	pH	T, °F	Wt % Solids	Gypsum Relative Saturation
Service Water (Condenser Outlet)	10/22 p.m.	36.6	7.9	3.0	1.7	1.9	17.3†	3.2†	119	7.4	90	-	.003†
	10/23 a.m.	33.5	7.8	3.1	1.9	2.0			116	7.2	79	-	
	10/23 p.m.	33.2	7.8	2.7	1.8	1.7			115	7.6	89	-	
	10/24 a.m.	33.2	7.7	2.8	1.7	1.7			119	7.5	87	-	
Bottom Ash Slurry	10/22 p.m.	36.4	8.1	3.0	2.2	2.5	39.4†	3.2†	104	6.4	118	1.07	.008
	10/23 a.m.	34.3	7.8	2.9	1.8	2.0			133	6.8	91	2.74	.008
	10/23 p.m.	35.8	8.0	2.8	2.1	2.3			116	6.8	100	2.88	.008
	10/24 a.m.	34.3	8.0	2.9	2.3	2.5			115	6.2	108	3.41	.008
Fly Ash Slurry	10/22 p.m.	43.5	9.1	4.9	8.1	3.0	163†	3.2†	84	4.7	92	5.37	.030
	10/23 a.m.	42.1	9.0	4.1	7.3	2.2			115	5.0	90	6.01	.030
	10/23 p.m.	42.6	9.2	4.4	8.1	2.4			117	5.3	91	4.45	.030
	10/24 a.m.	44.7	9.5	4.5	9.4	10.9			117	4.3	87	2.45	.031
Pond Discharge	10/22 p.m.	38.8	8.6	3.4	3.3	2.4	61.4†	3.6†	76.2	8.2	76	-	.012
	10/23 a.m.	38.9	8.5	3.5	3.2	2.1			82.2	8.2	70	-	.012
	10/23 p.m.	38.4	8.6	3.5	3.2	2.1			75.6	8.4	70	-	.012
	10/24 a.m.	38.7	8.6	3.6	3.2	2.1			80.4	8.0	66	-	.012
Old Precipitator (not energized) Ash Sluice	10/23 a.m.	33.8	8.0	3.0	2.0	2.6	30.7†	3.2†	152	6.3	88	0.34	.006
	10/23 p.m.	34.0	7.9	3.1	2.1	1.8			143	6.5	90	0.34	.006
	10/24 a.m.	33.9	7.7	2.9	1.9	1.8			130	6.7	92	0.14	.006

[*] All analyses except Cℓ, SO_4, CO_3 performed by inductively coupled argon plasma emission spectroscopy (ICAPES). Cℓ, SO_4 analyses performed by ion chromatography. Carbonate analyses performed by non-dispersive IR.

†Analyses performed on composite samples.

TABLE E-1.6. COMPOSITE SAMPLE ANALYSES FOR PLANT 4424 (13 INORGANIC PRIORITY POLLUTANTS, mg/ℓ)*

Sample Point	Ag	Be	Cd	Cr	Cu	Ni	Zn	As	Se	Sb	Hg	Pb	Tl
Service Water (Condenser Outlet)	<.002	<.001	<.001	<.002	.018	<.030	.038	<.005	<.005	<.005	<.001	.008	<.002
Bottom Ash Slurry	<.002	<.001	<.001	<.002	.010	<.030	.030	<.005	<.005	<.005	<.001	.005	<.002
Fly Ash Slurry	<.002	.003	.008	.087	.170	<.030	.270	.245	.367	.032	<.001	.006	<.002
Pond Discharge	<.002	<.001	<.001	<.002	.017	.030	<.020	.019	.086	<.005	<.001	.002	<.002
Old Precipitator (not energized) Ash Sluice	<.002	<.001	.005	<.002	.018	.060	.049	.008	.019	<.005	<.001	<.002	<.002

*All sample analyses performed by atomic absorption

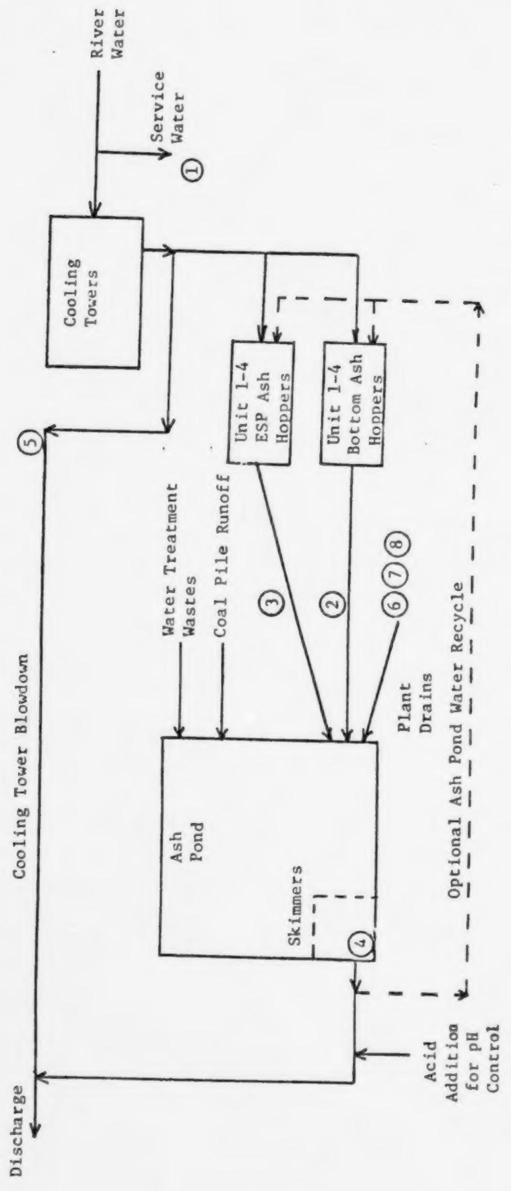

River Water
Service Water
①
Cooling Towers
Unit 1-4 ESP Ash Hoppers
Unit 1-4 Bottom Ash Hoppers
⑤
Cooling Tower Blowdown
Water Treatment Wastes
Coal Pile Runoff
③
②
⑥⑦⑧
Plant Drains
Optional Ash Pond Water Recycle
Ash Pond
Skimmers
④
Acid Addition for pH Control
Discharge

Figure E-1.2. Plant 9677 Ash Disposal Block Diagram and Sample Points

TABLE E-1.7. COAL AND ASH ANALYSIS FOR PLANT 9677

Coal Ultimate Analysis

Species	Wt %
Moisture	10.25
Carbon	64.63
Hydrogen	4.45
Nitrogen	1.49
Chlorine	0.05
Sulfur	1.89
Ash	11.07
Oxygen (diff)	6.17
	100.00

Heating Value = 11,630 Btu/lb

Ash Mineral Analysis

Species	
SiO_2	51.67
Al_2O_3	23.67
TiO_2	1.17
Fe_2O_3	13.55
MgO	1.26
CaO	2.35
K_2O	2.80
Na_2O	0.54
SrO	0.00
BaO	0.09
SO_3	0.87

TABLE E-1.8 SAMPLE ANALYSES FOR PLANT 9677 (MAJOR SPECIES, mg/ℓ)*

Sample Point	Date	Ca	Mg	Na	K	Si	SO_4	Cℓ	CO_3	pH	T, °F	Wt % Solids	Gypsum Relative Saturation
Service Water	10/29 p.m.	11.8	2.1	3.7	1.7	5.0	8.6†	3.2†	28.8	7.2	66	-	.001†
	10/30 a.m.	8.5	1.9	2.8	1.4	4.8			29.4	6.9	62	-	
	10/31 a.m.	8.2	1.9	2.7	1.3	4.9			33.6	7.0	62	-	
Bottom Ash Slurry	10/29 p.m.	22.9	3.0	4.6	2.1	7.9	16.3	5.0	60.6	7.2	83	0.65	.002
	10/30 a.m.	43.4	2.9	4.8	2.6	7.7	78.7	4.6	60.0	6.2	96	2.60	.017
	10/30 p.m.	38.6	3.0	4.0	2.4	8.5	56.6	5.3	62.4	6.5	98	0.44	.012
	10/31 a.m.	64.5	2.8	15.9	5.5	6.0	180.0	5.7	55.2	4.0	98	7.94	.046
Fly Ash Slurry	10/29 a.m.	322.	7.1	10.9	19.1	3.3	484.0	5.7	19.2	6.3	81.5	6.20	.298
	10/29 p.m.	257.	5.1	11.8	20.9	3.0	396.0	5.0	26.4	9.8	84	7.78	.218
	10/30 a.m.	297.	7.8	12.7	22.5	9.7	601.0	6.0	23.4	4.7	79	6.80	.334
	10/30 p.m.	163.	4.3	6.4	10.5	4.6	223.0	6.0	38.4	9.6	85	3.15	.103
	10/31 a.m.	97.7	3.7	18.8	8.0	10.3	227.0	6.0	28.2	5.6	64	0.37	.078
Ash Pond Water	10/29 a.m.	89.2	3.2	18.6	6.3	6.0	182.0†	6.4†	21.6	9.7	64	-	.059
	10/29 p.m.	85.7	3.3	21.2	6.9	5.6			18.0	9.6	64	-	.058
	10/30 a.m.	52.6	3.2	24.6	8.7	4.5			21.6	9.6	62	-	.039
	10/30 p.m.	55.0	3.3	24.7	8.8	4.9			19.8	9.5	64	-	.040
	10/31 a.m.	57.7	3.2	23.2	7.8	4.7			25.8	9.5	64	-	.042
Circulating Cooling Water	10/29 p.m.	16.4	3.2	3.1	2.2	7.3	10.6†	5.0†	60.0	8.2	77	-	.001
	10/30 a.m.	18.7	3.3	3.3	2.3	7.8			66.6	8.2	80	-	.001
	10/31 a.m.	24.8	4.0	4.9	3.1	10.0			85.2	8.4	82	-	.002
Miscellaneous Plant Drain 1	10/29 a.m.	17.6	1.1	46.9	2.5	3.5	66.2†	5.3†	43.2	9.6	72	.24	.006
	10/29 p.m.	13.1	1.5	23.8	2.2	3.6			39.0	9.5	72	.80	.005
Miscellaneous Plant Drain 2	10/30 a.m.	15.2	3.0	2.8	1.6	4.3	24.0†	3.9†	33.6	6.7	75	.08	.002
	10/30 p.m.	14.3	2.3	4.0	1.7	4.5			42.0	8.2	69	.21	.002
Miscellaneous Plant Drain 3	10/31 a.m.	16.0	2.5	4.5	2.2	7.2	14.4	5.0	52.2	7.6	78	-	.002

*All analyses except SO_4, Cℓ, CO_3 performed with inductively coupled argon plasma emission spectroscopy (ICAPES). SO_4, Cℓ analyses performed by ion chromatography, carbonate analyses performed by non-dispersive IR.

†Analyses performed on composite samples.

TABLE E-1.9 COMPOSITE SAMPLE ANALYSES FOR PLANT 9677 (13 INORGANIC PRIORITY POLLUTANTS, mg/ℓ)*

Sample Point	Ag	Be	Cd	Cr	Cu	Ni	Zn	As	Se	Sb	Hg	Pb	Tℓ
Service Water	<.002	<.001	<.001	<.002	.005	<.030	<.020	.007	<.005	<.002	<.001	.005	<.002
Bottom Ash Slurry	<.002	<.001	<.001	<.002	.026	<.030	<.020	.016	<.005	<.002	<.001	.005	<.002
Fly Ash Slurry (a.m.)	<.002	<.001	.014	.014	.140	.040	.162	.102	.011	.020	<.001	.006	.009
Fly Ash Slurry (p.m.)	<.002	<.001	<.001	.043	.014	<.030	.040	.417	.035	.031	<.001	<.002	<.002
Ash Pond Water	<.002	<.001	.001	.003	.016	.080	<.020	.221	.006	.008	<.001	.002	<.002
Circulating Cooling Water	<.002	<.001	<.001	<.002	.060	<.030	<.020	<.005	<.005	<.002	<.001	.013	<.002
Miscellaneous Plant Drain 1	<.002	<.001	<.001	<.002	.069	<.030	<.020	.073	<.005	.005	<.001	.002	<.002
Miscellaneous Plant Drain 2	<.002	<.001	<.001	<.002	.009	<.030	<.020	.016	<.005	<.002	<.001	<.002	<.002
Miscellaneous Plant Drain 3	<.002	<.001	.001	<.002	.021	<.030	<.020	.006	<.005	<.002	<.001	<.002	<.002

*All analyses performed by atomic absorption

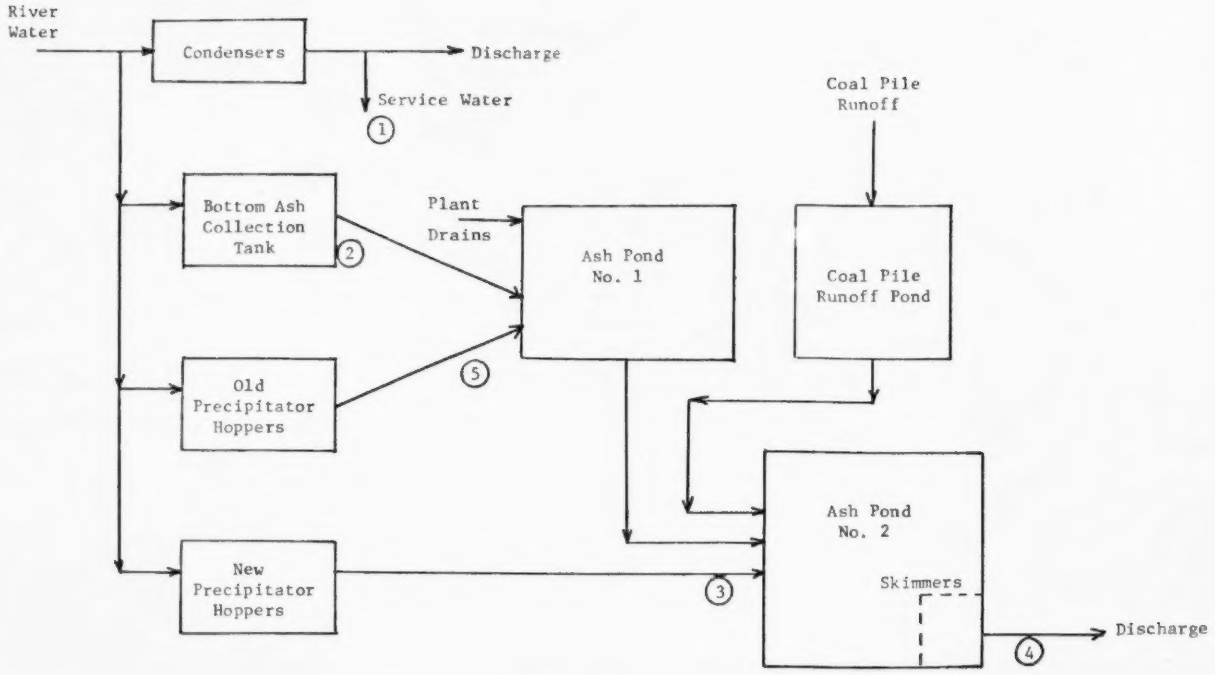

River Water
Condensers
Discharge
Service Water
①
Bottom Ash Collection Tank
②
Old Precipitator Hoppers
⑤
New Precipitator Hoppers
Plant Drains
Ash Pond No. 1
Coal Pile Runoff
Coal Pile Runoff Pond
Ash Pond No. 2
Skimmers
③
④
Discharge

Figure E-1.3. Plant 4424 Ash Handling System Block Diagram and Sample Points

APPENDIX E.2

BENCH SCALE DATA

This appendix presents the analysis of samples taken during the bench scale sluicing test runs. As stated earlier, the runs were not long enough to reach steady-state conditions; therefore, this data was used to predict steady-state concentrations of the soluble major species. Tables E.2-1, E.2-2, and E.2-3 are the major species analysis for the nine runs. Tables E.2-4, E.2-5, and E.2-6 give the concentrations of 12 inorganic priority pollutants during the runs. Mercury was not analyzed in these tests. Figures E.2-1 through E.2-9 plot the calcium and sulfate concentrations and gypsum relative saturation as a function of time for each of the nine runs.

TABLE E-2.1. PLANT 1873 SLUICING RESULTS - MAJOR SPECIES (mg/ℓ)*

Run	Sample time†	pH	Ca	Mg	Na	K	SO_4	Cl	CO_3	Si
1	0	3.05	134.	17.1	16.4	33.7	558.	12.	16.	12.3
	6	3.00	364.	35.9	28.1	45.9	1540.	13.	60.	27.1
	11	2.95	514.	47.0	35.8	62.7	2100.	12.	52.	39.3
	18	2.95	638.	56.4	46.8	85.3	2690.	12.	11.	54.6
	24	2.95	781.	63.0	55.2	102.	3110.	15.	18.	66.5
	30	2.90	1030.	71.8	53.7	99.0	3480.	13.	19.	78.5
2	0	3.05	1190.	79.7	52.7	99.1	3680.	12.	20.	87.1
	6	3.10	1150	83.5	50.4	97.9	3490.	12.	32.	89.8
	12	3.05	1180.	78.6	44.5	86.9	3440.	9.	20.	84.8
	18	3.00	1140.	73.0	39.1	75.0	3200.	8.	21.	75.9
	24	3.15	1070.	69.4	37.6	71.2	3070.	7.	32.	70.4
	30	3.15	1130.	68.9	34.6	66.3	2970.	8.	59.	69.8
3	0	3.40	1120.	75.5	40.5	77.2	3230.	9.	20.	76.9
	6	3.50	1032.	69.2	37.6	73.0	2940.	9.	40.	69.8
	11	3.45	1030.	65.2	34.5	66.9	2800.	8.	70.	66.0
	18	3.50	1050.	62.4	32.6	63.4	2700.	7.	76.	62.1
	24	3.50	1030.	60.2	31.0	60.0	2470.	7.	68.	58.2
	30	3.45	1020.	61.4	30.6	57.2	2450.	7.	62.	50.7
	Makeup Water	7.5	17.7	1.96	6.79	2.49	28.	6.	36.	1.8

*Ca, Mg, Na, K, Si analysis performed by Inductively Coupled Argon Plasma Emission Spectroscopy; SO_4, Cl analysis performed by Ion Chromatography; CO_3 analysis performed by non-dispersive I.R.

†Hours after run started.

TABLE E-2.2. PLANT 4424 SLUICING RESULTS - MAJOR SPECIES (mg/ℓ)*

Run	Sample time†	pH	Ca	Mg	Na	K	SO_4	Cl	CO_3	Si
4	0	3.70	114.	21.6	14.2	44.6	675.	19.	116.	13.8
	.25	3.75	117.	22.0	14.2	44.8	683.	16.	104.	14.3
	.75	3.83	118.	21.9	14.0	44.1	687.	16.	140.	14.3
	1.75	3.83	118.	22.1	14.0	44.2	740.	19.	114.	14.5
	3.75	3.81	120.	22.4	14.5	45.2	755.	45.	111.	14.7
	7.78	3.70	127.	23.4	14.8	47.7	828.	19.	85.	14.7
	15.75	3.54	136.	25.2	16.8	55.5	970.	26.	115.	14.9
	30	3.27	152.	28.1	20.0	67.9	1150.	28.	208.	16.5
	40	3.13	161.	29.0	21.6	73.5	1250.	33.	313.	17.6
	50	3.20	170.	29.9	22.8	78.2	1330.	30.	232.	18.6
5	0	3.40	198.	31.5	23.0	80.6	1360.	34.	216.	25.1
	6	3.45	194.	37.8	22.2	75.5	1290.	30.	227.	24.1
	12	3.50	183.	30.3	22.2	74.6	1260.	30.	212.	22.4
	18	3.60	180.	29.3	21.5	74.0	1250.	29.	257.	21.5
	24	3.50	178.	30.8	21.8	73.8	1250.	31.	206.	20.8
	30	3.50	170.	29.6	21.6	72.3	1280.	29.	224.	19.5
6	0	3.50	181.	31.4	22.3	74.0	1290.	30.	184.	21.6
	6	3.55	171.	29.8	20.8	68.9	1220.	26.	193.	20.3
	11	3.50	160.	28.3	19.8	64.6	1120.	25.	185.	18.9
	18	3.50	144.	25.9	18.2	58.2	1010.	24.	151.	16.7
	24	3.55	136.	24.5	16.6	53.1	924.	17.	118.	15.4
	26	3.55	134.	24.2	16.4	52.1	895.	17.	111.	15.1
	Makeup Water	7.4	32.4	9.12	3.61	1.88	19.	1.	116.	2.12

*Ca, Mg, Na, K, Si analysis performed by Inductively Coupled Argon Plasma Emission Spectroscopy; SO_4, Cl analysis performed by Ion Chromatography; CO_3 analysis performed by non-dispersive I.R.

†Hours after run started.

TABLE E-2.3. PLANT 9677 SLUICING RESULTS - MAJOR SPECIES (mg/ℓ)*

Run	Sample time†	pH	Ca	Mg	Na	K	SO_4	Cl	CO_3	Si
7	0	7.35	72.1	4.94	11.5	15.5	109.	4.	64.	6.82
	6	9.70	158.	7.27	22.5	31.8	200.	4.	41.	6.20
	12	9.80	238.	7.63	24.7	39.5	333.	4.	40.	2.82
	18	9.65	261.	6.57	22.8	41.7	451.	4.	39.	.820
	24	9.30	324.	7.79	28.1	48.4	546.	5.	31.	1.03
	30	9.30	328.	7.24	26.7	47.4	607.	4.	34.	.791
8	0	9.50	296.	5.97	28.9	49.8	607.	5.	29.	.949
	6	8.90	490.	5.58	38.3	68.1	780.	5.	55.	1.04
	12	8.70	500.	7.78	43.6	81.2	1030.	5.	40.	.861
	18	8.80	600.	9.44	47.6	88.7	1220.	5.	38.	1.02
	24	8.80	891.	11.8	62.2	113.	1310.	4.	44.	1.14
	30	8.85	927.	10.1	53.4	102.	1500.	4.	43.	1.04
9	0	9.00	621.	9.58	53.7	94.4	2010.	4.	58.	2.92
	6	8.90	696.	10.4	62.1	111.	2210.	5.	47.	2.64
	12	8.80	836.	14.2	64.9	117.	3040.	4.	26.	1.81
	18	8.30	930.	19.6	70.5	120.	4220.	5.	15.	2.48
	24	7.90	1030.	20.7	73.3	126.	3180.	4.	13.	3.35
	30	7.62	1070.	28.3	88.0	157.	2410.	6.	8.	5.45
	36	7.40	1200.	21.8	93.2	158.	2410.	6.	13.	2.64
	43	7.40	1340.	24.6	93.2	164.	2510.	5.	5.	3.30
	48	7.40	1320.	27.2	87.5	153.	2730.	6.	7.	3.37
	54	7.40	1370.	29.4	98.2	172.	2830.	6.	2.	3.62
	60	7.40	1430.	31.5	107.	188.	2870.	6.	5.	3.49
	Makeup Water	7.0	13.1	2.92	2.92	1.62	12.0	5.	64.	6.21

*Ca, Mg, Na, K, Si analysis performed by Inductively Coupled Argon Plasma Emission Spectroscopy; SO_4, Cl analysis performed by Ion Chromatography; CO_3 analysis performed by non-dispersive I.R.

†Hours after run started.

TABLE E-2.4. PLANT 1873 SLUICING RESULTS - 12 INORGANIC PRIORITY POLLUTANTS (mg/ℓ)*

Run	Sample time†	Ag	Be	Cd	Cr	Cu	Zn‡	Ni	As	Se	Sb	Pb	Tl
1	0	<.002	.017	.036	.074	.671	11.0	-	-	-	-	-	-
	6	<.002	.053	.078	.281	1.83	30.9	-	-	-	-	-	-
	11	<.002	.079	.108	.424	2.60	47.7	-	-	-	-	-	-
	18	<.002	.107	.139	.535	3.52	61.6	-	-	-	-	-	-
	24	<.002	.138	.167	.708	4.31	82.8	1.14	43.6	.005	.032	.007	.190
	30	.036	.169	.231	.981	4.78	106.3	1.17	47.7	.009	.051	.005	.180
2	0	.064	.180	.251	1.10	4.51	186.	-	-	-	-	-	-
	6	.069	.174	.258	1.00	4.10	182.	-	-	-	-	-	-
	12	.090	.168	.269	1.03	3.67	183.	-	-	-	-	-	-
	18	.105	.155	.268	1.01	3.34	165.	-	-	-	-	-	-
	24	.103	.145	.247	.943	3.14	153.	1.19	34.9	.003	.039	<.002	.180
	30	.119	.142	.250	.965	3.01	160.	1.10	30.7	.005	.035	.003	.160
3	0	.096	.146	.228	.881	2.80	238.	-	-	-	-	-	-
	6	.101	.131	.216	.732	2.43	218.	-	-	-	-	-	-
	11	.109	.126	.211	.702	2.29	226.	-	-	-	-	-	-
	18	.125	.121	.208	.695	2.14	242.	-	-	-	-	-	-
	24	.126	.114	.200	.679	2.08	239.	1.03	21.3	.003	.035	<.002	.150
	30	.147	.099	.258	.828	2.28	187.	.86	18.8	.005	.037	<.002	.131
	Makeup Water	<.002	<.001	<.008	<.007	.018	.442	-	-	-	-	-	-

*Samples not analyzed for mercury; Ag, Be, Cd, Cr, Cu, Zn analysis performed by Inductively Coupled Argon Plasma Emission Spectroscopy; Ni, As, Se, Sb, Pb, Tl analysis performed by Atomic Absorption.

†Hours after run started.

‡High zinc values probably due to corrosion of galvanized tank.

TABLE E-2.5. PLANT 4424 SLUICING RESULTS - 12 INORGANIC PRIORITY POLLUTANTS (mg/ℓ)*

Run	Sample time†	Ag	Be	Cd	Cr	Cu	Zn	Ni	As	Se	Sb	Pb	Tl
4	0	<.002	.021	.068	.609	1.30	1.02	-	-	-	-	-	-
	.25	<.002	.027	.061	.554	1.24	.994	-	-	-	-	-	-
	.75	<.002	.026	.067	.555	1.24	1.00	-	-	-	-	-	-
	1.75	<.002	.026	.060	.530	1.23	.995	-	-	-	-	-	-
	3.75	<.002	.029	.066	.507	1.21	1.05	-	-	-	-	-	-
	7.75	<.002	.037	.067	.541	1.28	1.17	-	-	-	-	-	-
	18.75	<.002	.047	.075	.772	1.56	1.39	-	-	-	-	-	-
	30	<.002	.052	.070	1.17	1.92	1.63	-	-	-	-	-	-
	40	<.002	.057	.077	1.43	2.14	1.71	.63	1.56	.120	.032	<.002	.041
	50	<.002	.057	.077	1.67	2.51	1.77	.75	1.97	.126	.039	.003	.049
5	0	<.002	.059	.087	1.42	2.18	5.46	-	-	-	-	-	-
	6	<.002	.057	.072	1.32	2.07	6.58	-	-	-	-	-	-
	12	<.002	.055	.071	1.31	2.05	5.84	-	-	-	-	-	-
	18	<.002	.056	.072	1.37	2.06	5.41	-	-	-	-	-	-
	24	<.002	.056	.076	1.45	2.07	5.14	.68	1.04	.077	.030	<.002	.048
	30	<.002	.057	.083	1.58	2.09	4.53	.61	1.12	.076	.033	<.002	.043
6	0	<.002	.057	.068	1.59	2.12	4.73	-	-	-	-	-	-
	6	<.002	.051	.065	1.44	1.92	4.61	-	-	-	-	-	-
	12	<.002	.047	.052	1.35	1.80	4.24	-	-	-	-	-	-
	18	<.002	.042	.056	1.23	1.73	3.54	-	-	-	-	-	-
	24	<.002	.040	.052	1.18	1.62	3.20	.48	.77	.058	.027	<.002	.030
	26	<.002	.038	.051	1.15	1.59	3.10	.44	.79	.060	.028	<.002	.027
	Makeup Water	<.002	<.001	<.008	<.007	.015	.022	-	-	-	-	-	-

*Samples not analyzed for mercury; Ag, Be, Cd, Cr, Cu, Zn analysis performed by Inductively Coupled Argon Plasma Emission Spectroscopy; Ni, As, Se, Sb, Pb, Tl analysis performed by Atomic Absorption.

†Hours after run started.

TABLE E-2.6. PLANT 9677 SLUICING RESULTS - 12 INORGANIC PRIORITY POLLUTANTS (mg/ℓ)*

Run	Sample time†	Ag	Be	Cd	Cr	Cu	Zn	Ni	As	Se	Sb	Pb	Tl
7	0	<.002	<.001	.107	.236	.074	.439	-	-	-	-	-	-
	6	<.002	<.001	.090	.254	.070	.189	-	-	-	-	-	-
	12	<.002	<.001	.098	.279	.067	.195	-	-	-	-	-	-
	18	<.002	<.001	.113	.342	.076	.196	-	-	-	-	-	-
	24	<.002	<.001	.122	.349	.081	.530	<.08	.120	.037	.061	<.002	.021
	30	<.002	<.001	.097	.325	.073	.167	<.08	.128	.038	.058	<.002	.025
8	0	<.002	<.001	.101	.374	.073	.189	-	-	-	-	-	-
	6	.030	<.001	.109	.413	.075	.201	-	-	-	-	-	-
	12	.025	<.001	.094	.386	.073	.171	-	-	-	-	-	-
	18	.033	<.001	.097	.386	.075	.157	-	-	-	-	-	-
	24	.061	<.001	.114	.434	.089	.213	<.08	.118	.053	.081	<.002	.030
	30	.101	<.001	.055	.336	.075	.193	<.08	.122	.055	.076	<.002	.028
9	0	.119	<.001	.131	.574	.121	.362	-	-	-	-	-	-
	6	.196	.006	.128	.605	.117	.320	-	-	-	-	-	-
	12	.280	.010	.124	.471	.117	.314	-	-	-	-	-	-
	18	.365	.013	.176	.632	.166	.380	-	-	-	-	-	-
	24	.498	.018	.255	.802	.222	.556	<.08	.112	.005	.660	<.002	.079
	30	.910	.037	.457	1.35	.375	.213	<.08	.121	.005	.480	<.002	.110
	36	.756	.027	.309	.830	.355	.469	-	-	-	-	-	-
	43	1.06	.038	.436	1.16	.498	.304	-	-	-	-	-	-
	48	1.01	.036	.405	1.13	.475	1.09	-	-	-	-	-	-
	54	1.23	.045	.485	1.32	.597	.611	<.08	.129	<.001	.380	<.002	.100
	60	1.10	.039	.417	1.25	.547	.289	<.08	.094	<.001	.490	.002	.110
	Makeup Water	<.002	<.001	<.008	<.007	<.001	<.013	-	-	-	-	-	-

*Samples not analyzed for mercury; As, Be, Cd, Cr, Cu, Zn analysis performed by Inductively Coupled Argon Emission Spectroscopy; Ni, As, Se, Sb, Pb, Tl analysis performed by Atomic Absorption.

†Hours after run started.

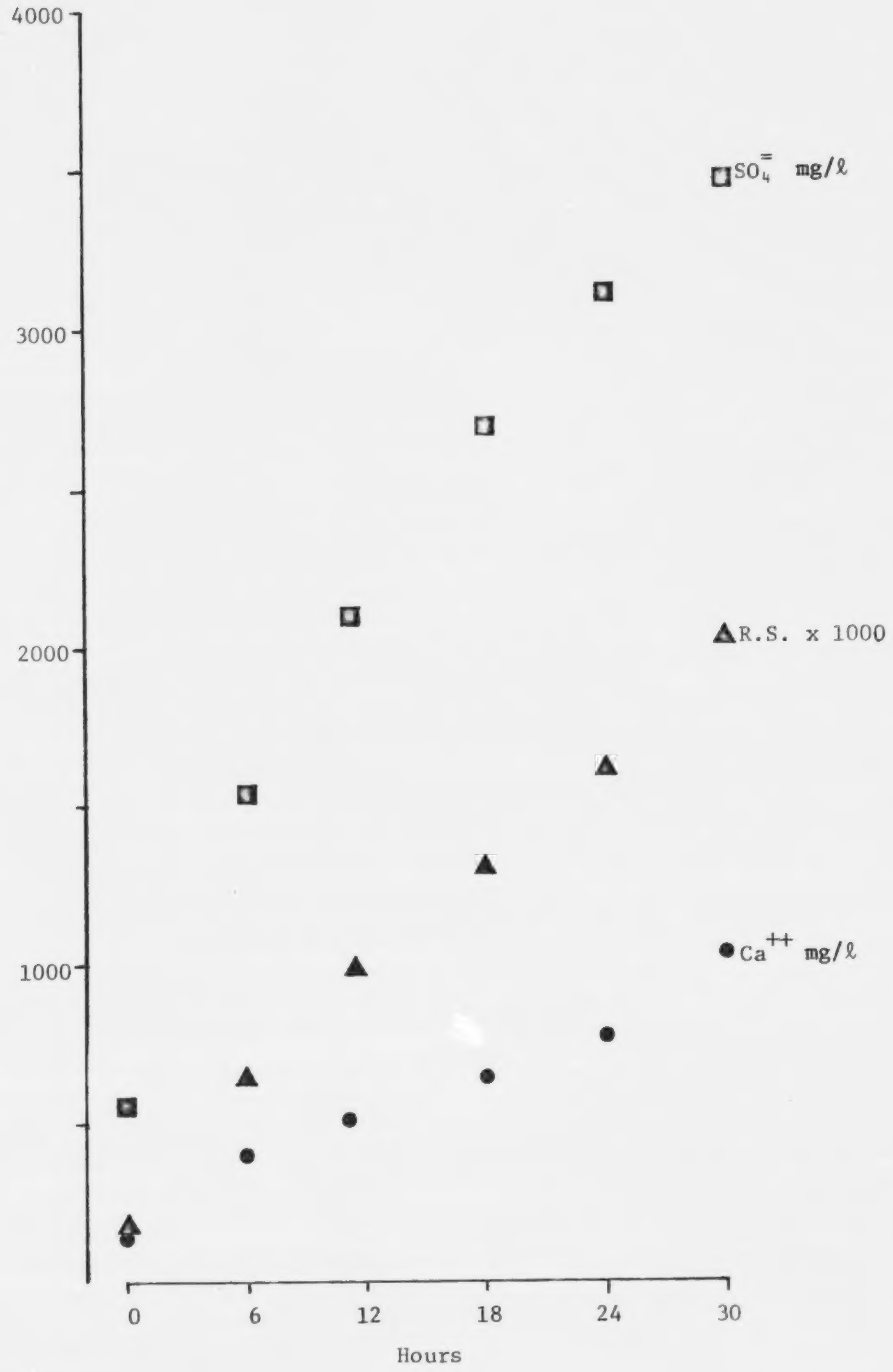


Figure E-2.1. Plant 1873 Run 1.

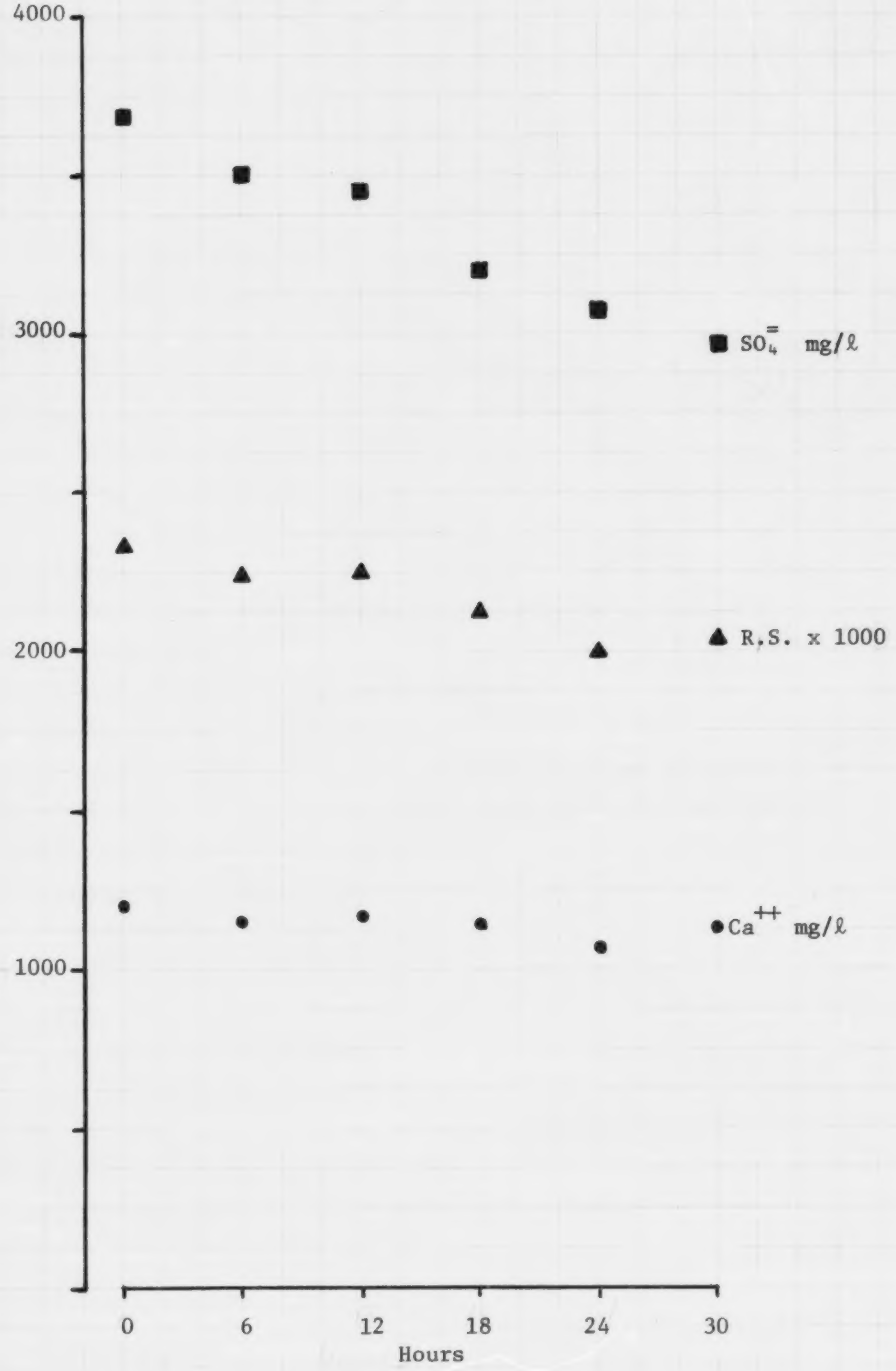


Figure E-2.2. Plant 1873 Run 2.

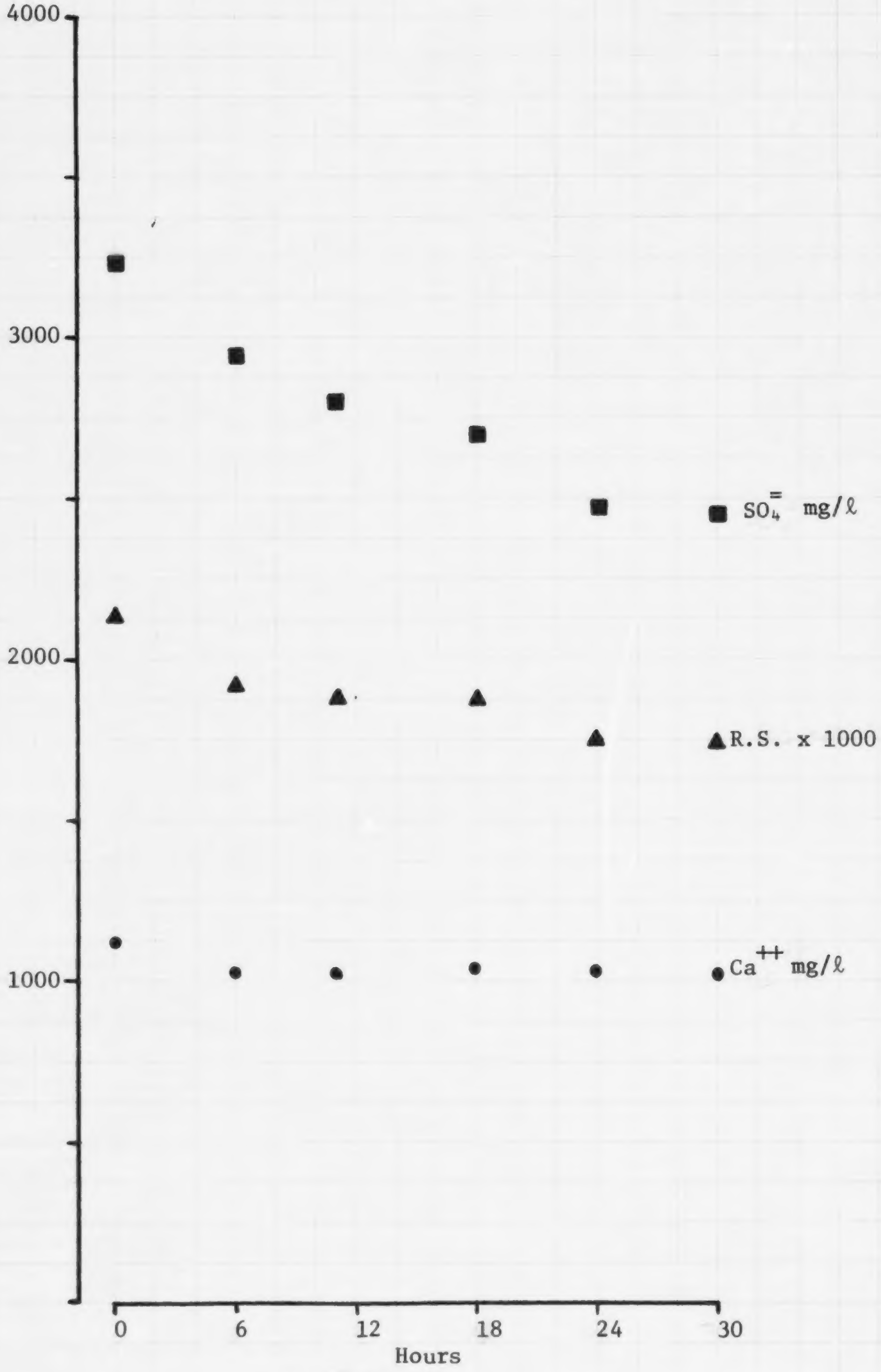


Figure E-2.3. Plant 1873 Run 3.

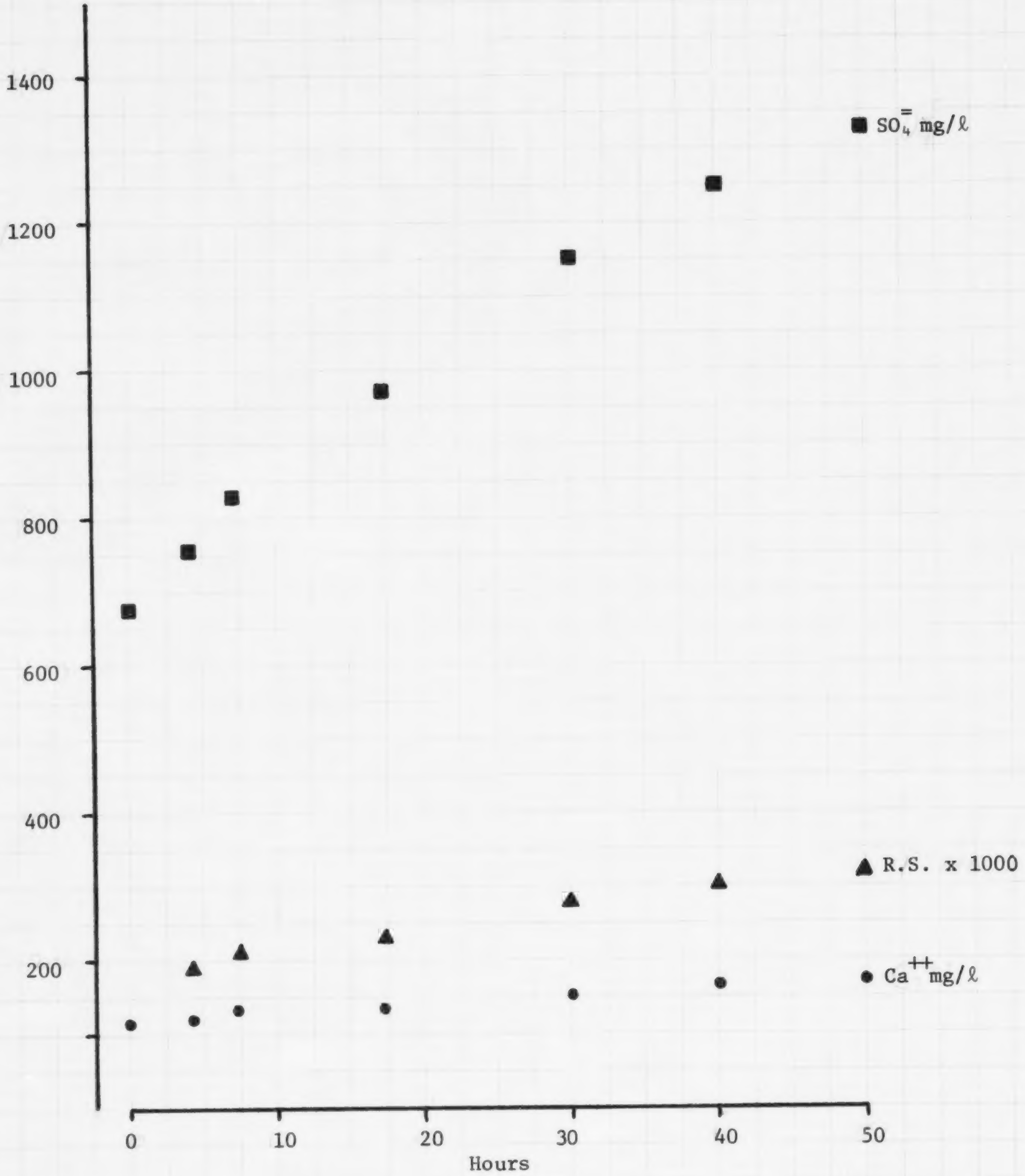


Figure E-2.4. Plant 4424 Run 4.

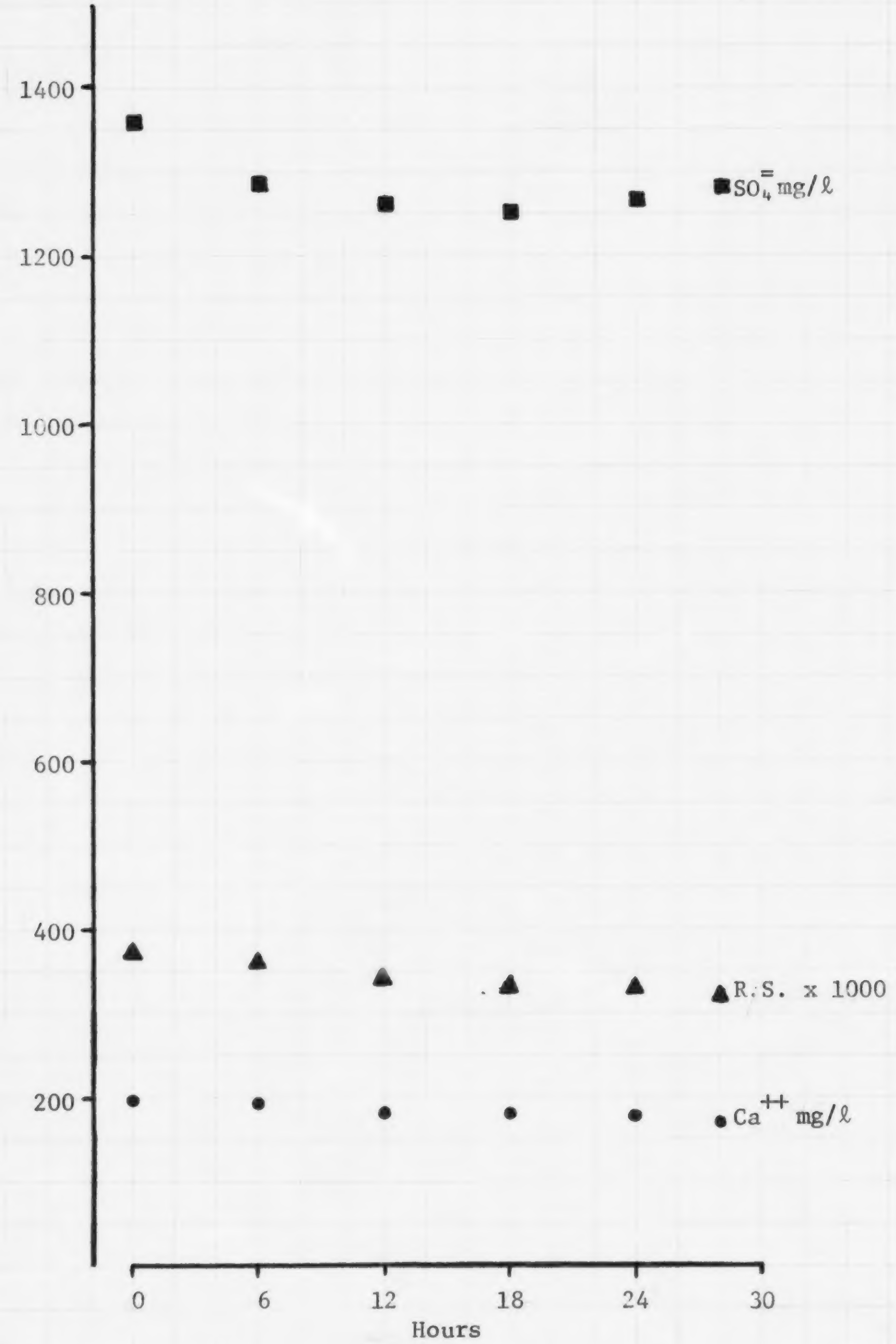


Figure E-2.5. Plant 4424 Run 5.

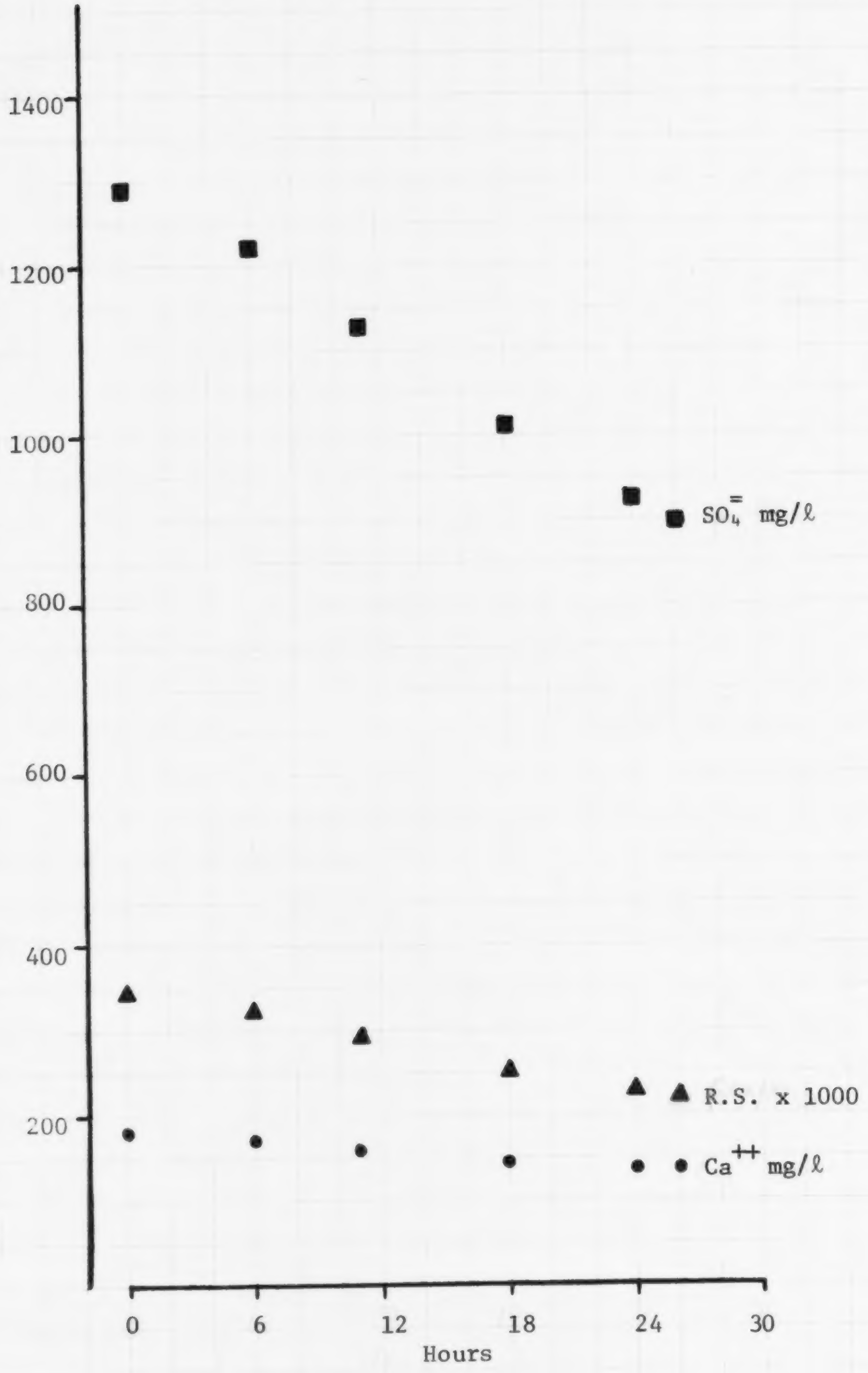


Figure E-2.6. Plant 4424 Run 6.

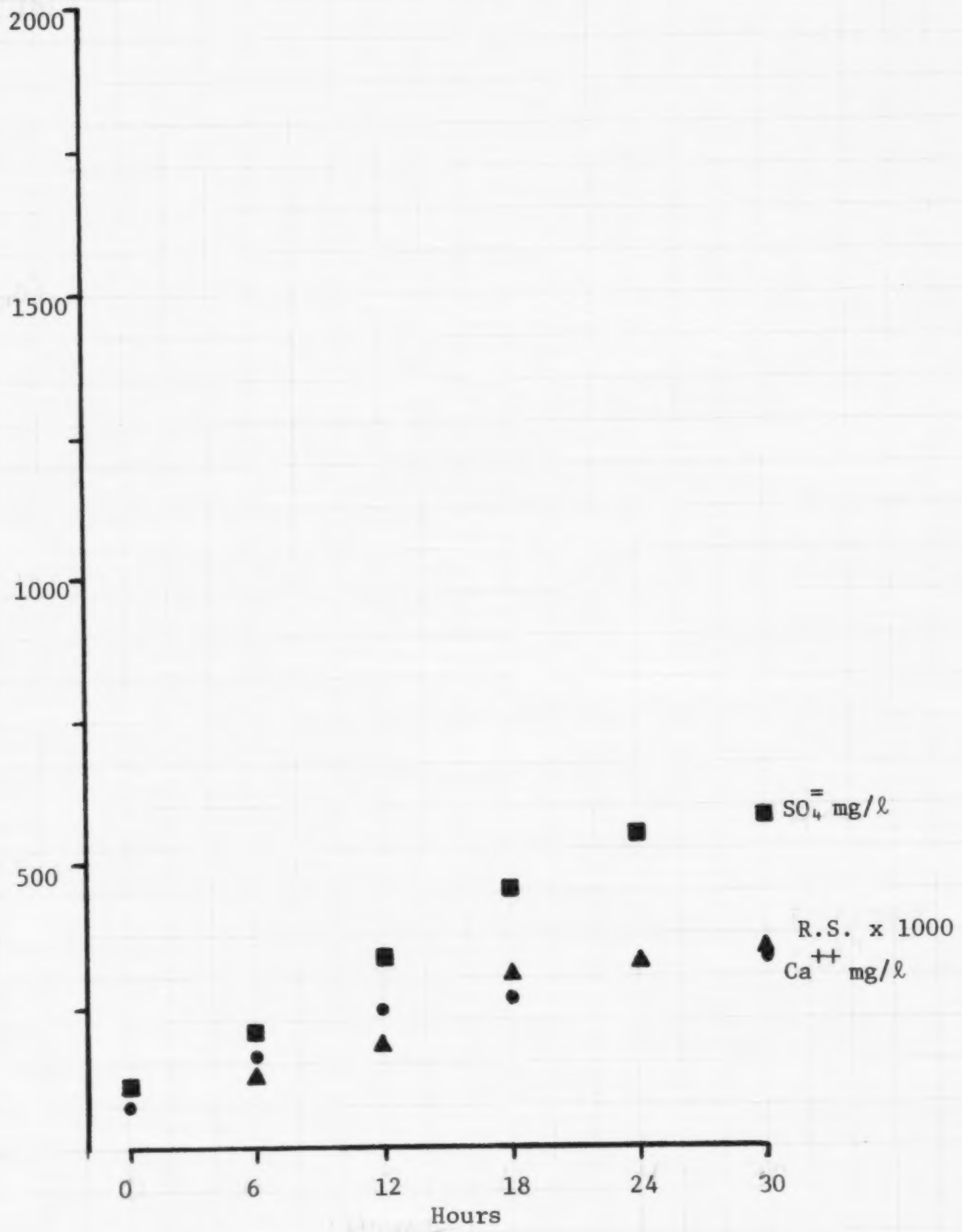


Figure E-2.7. Plant 9677 Run 7.

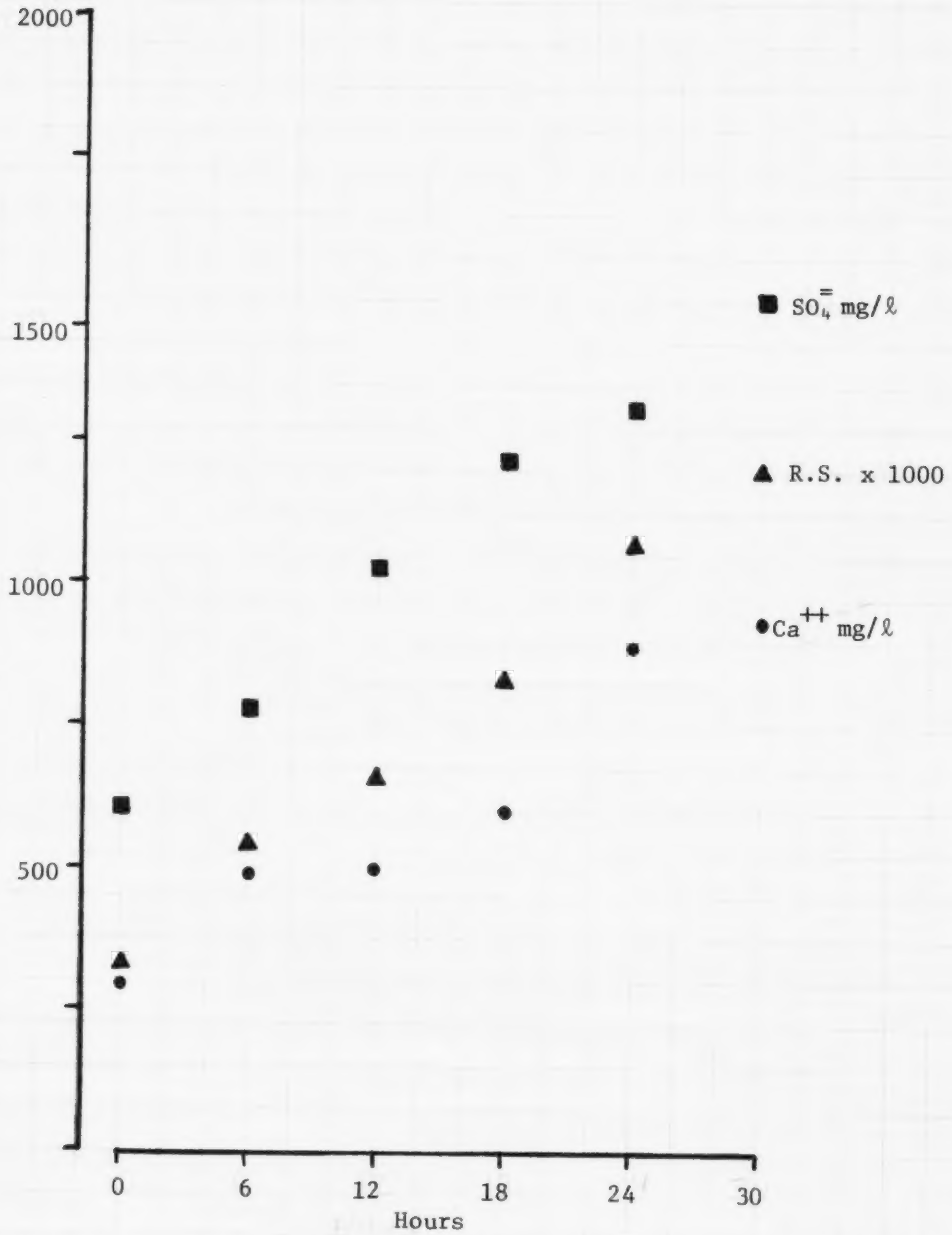


Figure E-2.8. Plant 9677 Run 8.

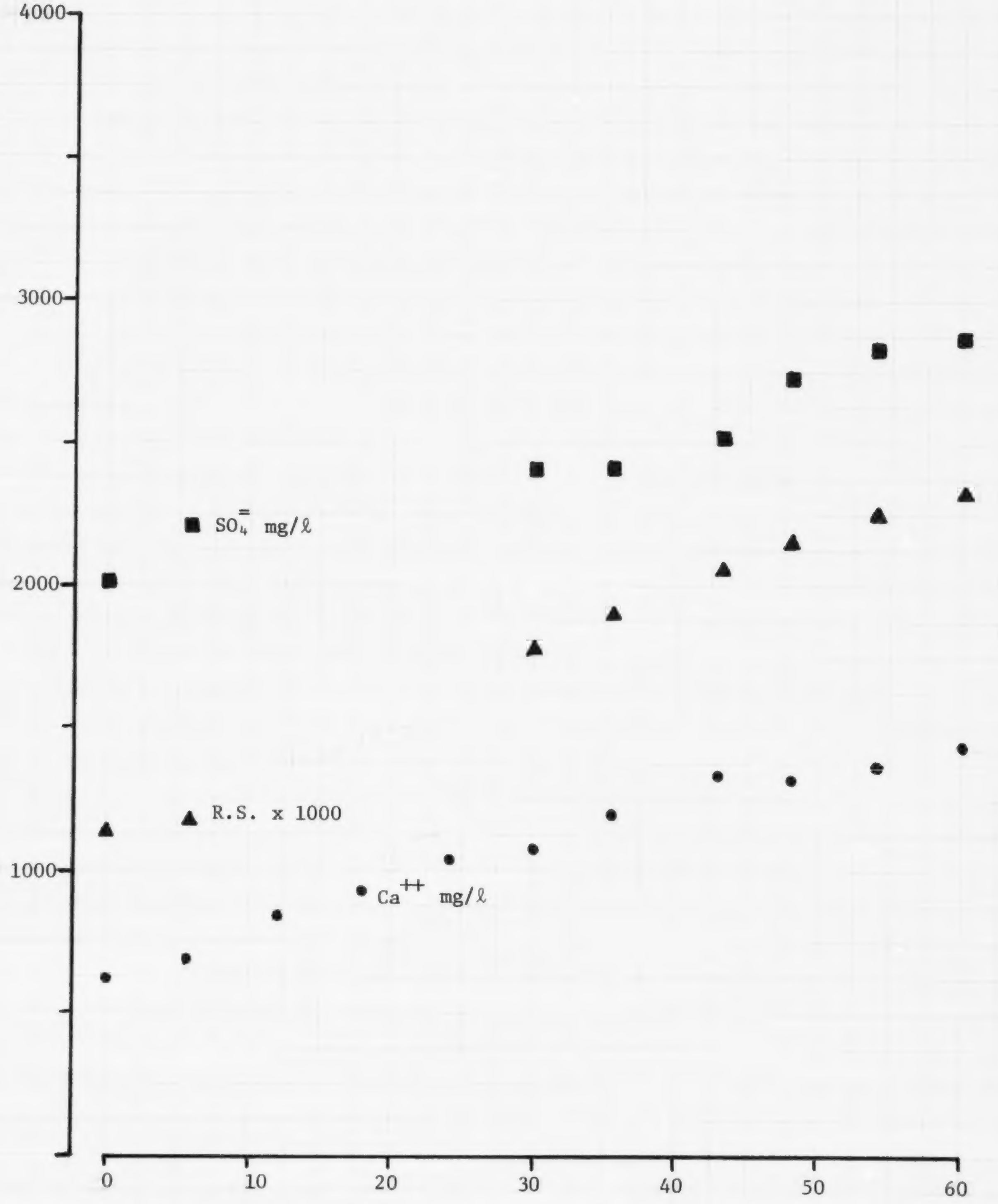


Figure E-2.9. Plant 9677 Run 9.

APPENDIX F

PILOT SCALE INVESTIGATION OF CLOSED-LOOP ASH SLUICING

FIELD TEST PLAN FOR PLANT 9677

DCN 81-211-004-21

PILOT SCALE INVESTIGATION OF CLOSED-LOOP ASH SLUICING

FIELD TEST PLAN FOR PLANT 9677

30 April 1981

by

RADIAN CORPORATION
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Austin, Texas 78759

for

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U.S. ENVIRONMENTAL PROTECTION AGENCY
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EPA Contract Number 68-02-3163

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SECTION 1

INTRODUCTION

1.1 BACKGROUND

The use of coal in steam-electric utility plants is predicted to increase in the coming years as supplies of natural gas and oil decline and become more expensive. However, unlike natural gas and oil, the combustion of coal produces significant amounts of solid waste in the form of fly ash and bottom ash. Frequently, utility plants will mix this ash with water and sluice the mixture to a large nearby pond. The ash will usually settle rapidly and clarified overflow water will be discharged to a stream or river.

The intimate mixing of fly ash and water causes soluble species (Ca, Mg, SO_4, and trace metals) to be leached from the ash increasing or decreasing the pH level. The discharge of pond water containing high levels of these dissolved species and suspended ash is environmentally unacceptable. One means of eliminating discharge from the pond is to recycle all overflow water for reuse as makeup to the ash sluice system. Yet as the concentrations of dissolved species increase in a closed-loop recycle system, the potential for scale formation in process lines and equipment also increases. Typically, the major scaling species are calcium carbonate ($CaCO_3$), gypsum ($CaSO_4 \cdot 2H_2O$), and silica salts. The potential for scale formation from these solid species can be controlled by various water treatment methods, such as pH adjustment and softening.

The U.S. Environmental Protection Agency has contracted Radian Corporation to evaluate the feasibility of operating closed-loop recirculating fly ash sluice water systems at coal-fired steam-electric utility plants. Radian has developed a two phase program for this purpose. Phase One focused on the development of a computer model designed to simulate a recirculating ash sluice water system and various water treatment options. In addition, bench scale lab studies were completed during Phase One to determine leachate rates from ash from Phase Two plants as input to the computer model. Phase Two involves the design, fabrication, and operation of a pilot scale closed-loop fly ash sluice water system at two existing power plants. The computer model will be used to determine preliminary operating conditions for the pilot unit field tests. Operating results from the pilot unit will be used to verify and/or modify the computer model and to evaluate the feasibility of recirculating fly ash sluice water.

This document presents the field test plan for operating the pilot unit and taking appropriate system characterization samples at Plant 9677.

1.2 FIELD TEST OBJECTIVES

The primary objective of the pilot unit field test program is to evaluate the technical feasibility of operating a closed-loop recirculating fly ash sluice water system at conditions very similar to those which might be encountered on a full-scale basis at the host site. A brief description of the water and wastewater system for the host site (Plant 9677) is presented in Appendix I.

The pilot unit will be operated at the minimum blowdown (maximum recycle) achievable with several levels of treatment:

- without any water treatment,
- allowing additional mixing/reaction time prior to sluicing,
- pH adjustment of the recycle water, and
- softening a portion or all of the recycle water.

Estimated minimum blowdown rates will be specified for testing by using the ash sluice computer model. Results from operating the pilot unit at these blowdown rates will be used to verify computer model predictions and to provide a basis for comparison of recycle water treatment alternatives.

1.3 FIELD TEST LIMITATIONS

The major limitation for all field tests will be the ability of the pilot unit to simulate the aqueous chemistry of a full scale ash pond. Instead of allowing the ash to settle, as in the case of a pond, the pilot unit will use a filter press to dewater the slurry. Essentially, the filter press differs from an ash pond in two respects: 1) the residence time and subsequent contact time for ash and water, and 2) the potential for CO_2 transfer between the atmosphere and the sluice water.

In a pond, large ash particles settle from the water fairly rapidly forming deltas. Some water will percolate through these large beds of ash, potentially allowing additional leaching. The small ash particles will eventually settle to form a sludge on the bottom of the pond. Water which is occluded with the ash sludge at the bottom of the pond, may also undergo additional leaching as if migrates into the ground. However, this water is technically removed from the pond and no longer contacts the clarified pond water.

In the case of the filter press, however, the ash is collected on a membrane as water is forced through both the membrane and the collected ash. Consequently, the ash is held in contact with the recycle water until removed from the filter. The estimated residence time for sluice water in the filter press is six minutes. The residence time for solids may range from one to eight hours.

The increased contact time between the ash and sluice water will probably result in the maximum leaching of soluble species. For the pilot unit, maximum leaching is desirable because the recirculating sluice water system will achieve steady-state operation more rapidly. The end result should not be significantly different since a similar steady-state condition is ultimately achieved in a pond.

In addition to the dissolution of certain species in the ash, the composition of the sluice water can be altered by CO_2 transfer between the pond and the atmosphere. For an alkaline ash, such as at Plant 9677, there is definite potential for CO_2 transfer. The pilot unit has no provision for CO_2 addition to the filter press effluent (ash pond overflow). However, laboratory bench tests performed using ash from Plant 9677 indicates that CO_2 transfer did not significantly affect the sluice water chemistry and, therefore, should not have a significant impact on test results from the pilot unit.

SECTION 2

FIELD TEST UNIT

The pilot field test unit consists of six portable skid-mounted equipment modules and one control/laboratory building. Each skid is approximately 2.4 by 3 meters (8 by 10 feet). The entire test system fits into an area no larger than 6.1 by 12.2 meters (20 by 40 feet). The pilot unit consists of four basic segments:

- a makeup/recycle tank, a fly ash storage bin and feeder, and a fly ash mixing tank to duplicate the slurrying process;
- a treatment reaction tank to allow additional mixing time prior to sluicing;
- a filter press to simulate the ash pond; and
- an acid feed system and a softener/clarifier to treat recycle water for the prevention/control of scale formation.

These skid-mounted equipment modules will be interconnected by flexible water hoses and electrical connections. An overall flow scheme of the pilot unit is presented in Figure 2-1.

In addition to the basic equipment modules, a test loop assembly is included to measure the scaling and corrosion effects in the sluice water recycle line. The test loop assembly will consist of two 5.1-cm (nominal 2-inch) diameter schedule 40 stainless steel pipe spools mounted in a parallel configuration. The spools will be identical 0.9 meter (3.0 foot) lengths, flanged for easy removal. The spools will be heat traced and insulated in order to maintain a wall temperature of 49°C (120°F). An ultrasonic pipe

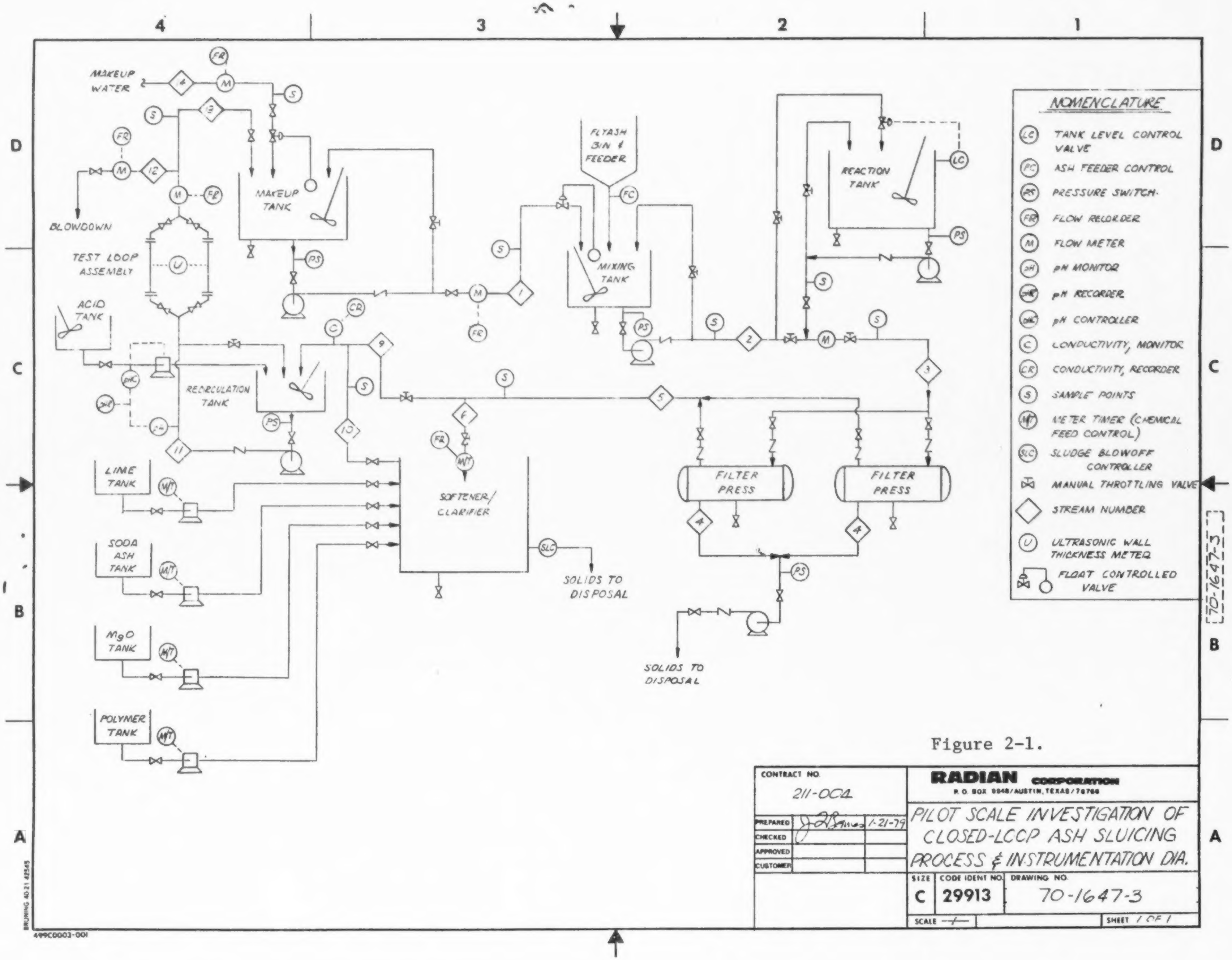
MAKEUP WATER
BLOWDOWN
TEST LOOP ASSEMBLY
ACID TANK
RECIRCULATION TANK
MAKEUP TANK
FLYASH BIN & FEEDER
MIXING TANK
REACTION TANK
SOFTENER/ CLARIFIER
FILTER PRESS
FILTER PRESS
SOLIDS TO DISPOSAL
SOLIDS TO DISPOSAL
LIME TANK
SODA ASH TANK
MgO TANK
POLYMER TANK
NOMENCLATURE
LC TANK LEVEL CONTROL VALVE
FC ASH FEEDER CONTROL
PS PRESSURE SWITCH
FR FLOW RECORDER
M FLOW METER
pH pH MONITOR
pH RECORDER
pH CONTROLLER
C CONDUCTIVITY, MONITOR
CR CONDUCTIVITY, RECORDER
S SAMPLE POINTS
M/T METER TIMER (CHEMICAL FEED CONTROL)
SLC SLUDGE BLOWOFF CONTROLLER
MANUAL THROTTLING VALVE
STREAM NUMBER
U ULTRASONIC WALL THICKNESS METER
FLOAT CONTROLLED VALVE
70-1647-3
CONTRACT NO. 211-OC4
PREPARED 1-21-79
CHECKED
APPROVED
CUSTOMER
RADIAN CORPORATION
P. O. BOX 9948/AUSTIN, TEXAS/78766
PILOT SCALE INVESTIGATION OF CLOSED-LCCP ASH SLUICING PROCESS & INSTRUMENTATION DIA.
SIZE C
CODE IDENT NO. 29913
DRAWING NO. 70-1647-3
SCALE —
SHEET 1 OF 1
BRUNING 40-21 42545
499C0003-001

Figure 2-1.

wall thickness gauge will be attached to the spool to monitor scaling or fouling. The parallel configuration is valved such that a spool can be easily removed for visual inspection.

Additional details on pilot unit equipment and operation is available in the Field Test Unit Operating Manual.

SECTION 3

FIELD TEST APPROACH

Field testing at Plant 9677 will consist of three separate sets of field test efforts. These sets are designed to evaluate the influence of sluicing different weight fractions of fly ash. Based on a constant liquid flow rate of 190 liters per minute (50 gpm), enough ash will be added to form a slurry containing 1.0, 5.0, and 10.0 weight percent solids. For each different slurry, a set of field tests will be completed to determine the minimum achievable blowdown:

- without any water treatment,
- with additional mixing/reaction time to allow precipitation prior to sluicing,
- with chemical treatment (sulfuric acid addition) to prevent scale formation in the recycle water line,
- with chemical treatment and sidestream softening to prevent scale formation in the recycle line.

Therefore, field testing at Plant 9677 will consist of three sets of four tests each or twelve individual pilot unit test conditions.

The basic approach for each test will be to use the ash sluice water computer model to estimate initial pilot unit operating conditions. Ash leaching data for the computer model will be provided from laboratory results of batch leaching studies performed with sample fly ash from Plant 9677 and deionized water. As the field tests proceed, these data can be supplemented by current field test data and additional computer simulation cases can be completed.

3.1 SAMPLING STRATEGY

During the course of field testing, two types of samples will be required. First, specified samples must be taken periodically to monitor the pilot unit for process upsets and to determine when steady-state operation is achieved. A list of these samples and other operating parameters to monitor for steady-state operation are presented in Table 3-1. Samples for all tests will be taken once every four hours. Each sample will not exceed 50 ml in volume. When the parameters listed in Table 3-1 show no significant variation over three sample periods (twelve hours), the pilot unit will be considered operating at steady-state.

Once the pilot unit has reached steady-state operation, a complete set of system characterization samples will be taken. These samples will be 250 ml in volume; 100 ml for analysis of major cations (Ca, Mg, Na, K, NH_4); 100 ml for analysis of major anions (Cl, SO_4, NO_3, SiO_2); and 50 ml for carbonate analysis. Additional details on sample analyses are provided in Section 4, Analytical Methods. System characterization samples will be taken at each major sample point listed in Table 3-2. In this way, each stream in the pilot unit can be fully characterized for steady-state operation at specified conditions. The unit will continue to operate for a period of 48 hours to verify steady-state operation, if required, then duplicate 250 ml samples will be taken for each point and appropriately preserved for analysis at a later date.

Samples will be taken at the beginning and the end of each test and retained for trace metal analysis (by Inductively Coupled Argon Plasma, ICAP) at Radian Laboratories in Austin, Texas.

3.2 FIELD TEST FOR MINIMUM BLOWDOWN WITH NO TREATMENT

The purpose of these tests is to determine the minimum blowdown rate achievable with no recycle water treatment. The minimum blowdown will most

TABLE 3-1. PARAMETERS TO MONITOR FOR STEADY-STATE OPERATION

Field Test	System Blowdown				Mix Tank Outlet			Reaction Tank Outlet			Makeup Water	Recycle Water		Softener Feed	Softener Blowdown				Softener Chemicals	
	Ca	Na	pH	Flow Rate	Ca	Na	pH	Ca	Na	pH	Flow Rate	pH	Flow Rate	Flow Rate	Ca	Na	pH	Flow Rate	Lime Flow Rate	Soda Ash Flow Rate
Minimum Blowdown (No Treatment)	✓	✓	✓	✓	✓	✓	✓				✓		✓							
Minimum Blowdown (Additional Ash Mixing Time)	✓	✓	✓	✓				✓	✓	✓	✓		✓							
Minimum Blowdown (Acid Addition)	✓	✓	✓	✓	✓	✓	✓				✓	✓	✓							
Minimum Blowdown (Softening and Acid Addition)	✓	✓	✓	✓	✓	✓	✓				✓	✓	✓	✓	✓	✓	✓	✓	✓	✓

TABLE 3-2. SAMPLES FOR PILOT UNIT SYSTEM CHARACTERIZATION

Sample Point ID	Sample Point Location
S-1	System Blowdown
S-2	Makeup Water
S-3	Mixing Tank Inlet Water
S-4	Mixing Tank Effluent
S-5	Reaction Tank Effluent
S-6	Filter Press Inlet
S-7	Filter Press Solids
S-8	Filter Press Effluent
S-9	Softener/Clarifier Solids
S-10	Softener/Clarifier Effluent
S-11	Recirculation Tank Inlet
S-12	Acid Tank
S-13	Lime Tank
S-14	Soda Ash Tank
S-15	MgO Tank

likely be limited by the precipitation of either calcium carbonate or gypsum in the recycle line. Using ash leaching data obtained from lab studies on sample fly ash from Plant 9677, a series of computer simulation cases was completed to evaluate the potential for calcium carbonate and/or gypsum solids formation as a function of blowdown. These simulation cases were for a slurry containing 1.0 weight percent ash and assumed no solids formation at any point in the system. The results are presented in Figure 3-1.

As reflected by the high calcium carbonate relative saturation levels, the potential for $CaCO_3$ precipitation in the filter press and/or recycle line is significant, even at high blowdown rates. This is true because high levels of calcium are leached from the ash, even though CO_2 transfer between the pond and the atmosphere is minimal. Therefore, initially the pilot unit will be operated as a once-through system, i.e., maximum system blowdown with no sluice water recycle during preliminary testing. Once-through operation is a conservative approach to evaluating the actual tendency of $CaCO_3$ precipitation. If no precipitation occurs in the recycle line, the blowdown can be gradually reduced meaning a similarly gradual increase in the sluice water recycle. By reducing the blowdown, the concentration of sparingly soluble salts, such as calcium carbonate, is increased until eventually precipitation will occur in the recycle line. The point at which precipitation occurs will be the minimum blowdown achievable without water treatment.

If anticipated precipitation occurs in the fly ash mixing tank, sluice line, or filter press, the aqueous concentration of critical dissolved species such as calcium may be reduced substantially. The precipitated solids will be removed with the fly ash in the filter press much the same as if the solids had settled in the ash pond. With a lower concentration of calcium in the recycle water, calcium carbonate precipitation may not be a problem in the recycle line. The degree of solids precipitation which will occur prior to the recycle line is difficult to predict. However, by measuring the calcium concentration of the filter press inlet and effluent, a reasonable estimate of the calcium removed as a solid can be made.

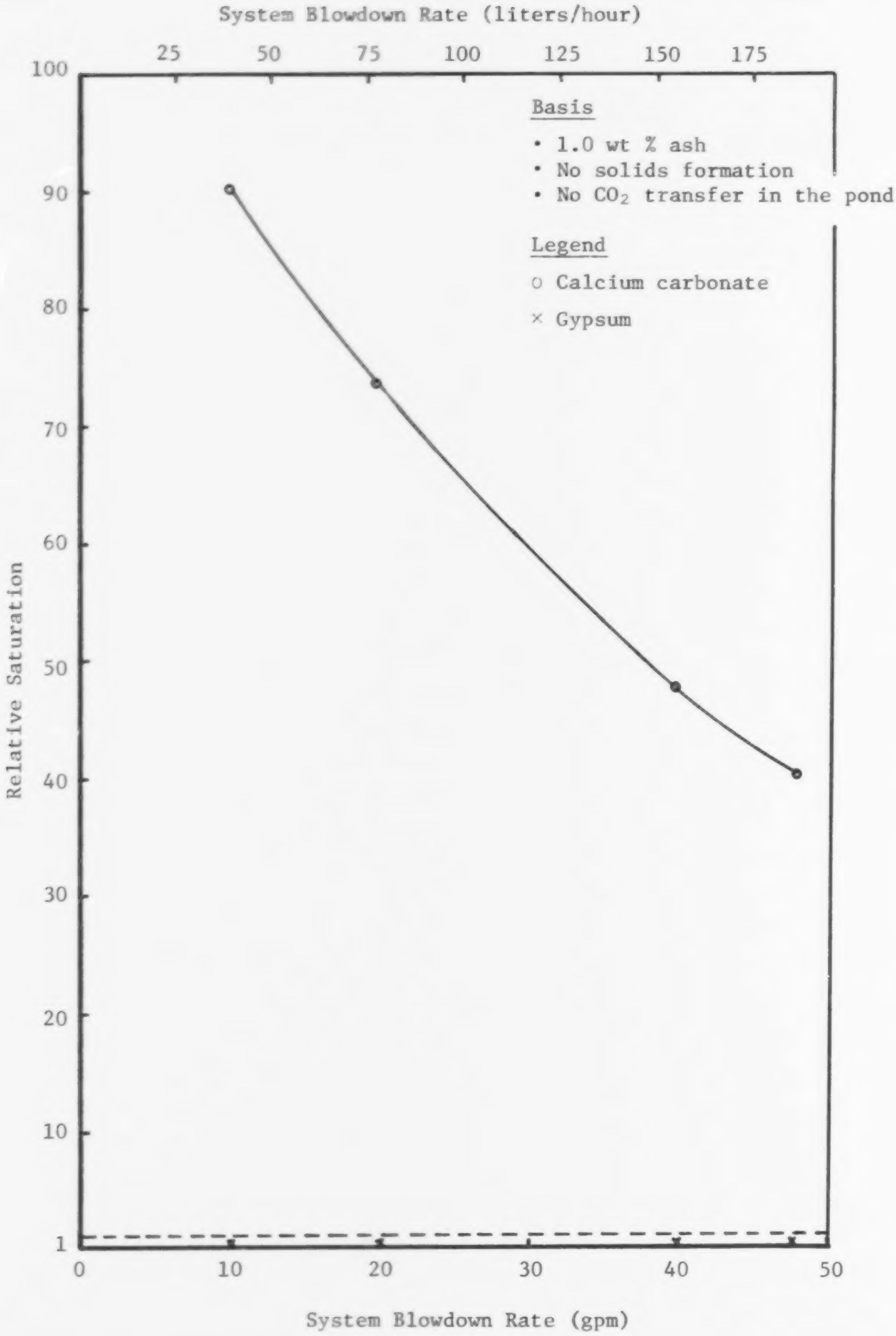

Figure 3-1. Predicted relative saturations of calcium carbonate and gypsum as a function of system blowdown rate.

Data obtained from sampling and analytical efforts in the field will be relayed to Radian's Austin office by telephone for interpretation and input to the computer model. This data transfer will occur as soon as the on-site information has been reviewed by the lead engineer/lead chemist for errors and/or inconsistencies. Results of any new computer modeling efforts will then be telephoned to field personnel for better operating control of the test unit.

Using these data, an approach to solid-liquid equilibrium can be estimated. A 90% approach to equilibrium means that only 90% of the calcium carbonate which would normally precipitate at equilibrium conditions, actually forms in the sluice system. Consequently, a 90% approach to solid-liquid equilibrium still results in a supersaturated condition, although the driving force for solids precipitation (as measured by the relative saturation) is significantly reduced. Using the estimated approach to equilibrium as an input to the computer model, a new set of simulation cases comparing $CaCO_3$ relative saturation and blowdown rate can be completed.

For any case in which the approach to solid-liquid equilibrium is less than 100%, the system will always remain supersaturated to some degree. However, the relative saturation may be below the "critical" value for solids formation, as shown in Figure 3-2. Chemical precipitation can occur by two mechanisms: (1) crystal growth on existing solids and (2) nucleation (i.e., the formation of new crystals from a clear solution). These mechanisms can be correlated to relative saturation, as illustrated in Figure 3-3 for calcium carbonate. The crystal growth mechanism predominates up to a critical relative saturation value. For calcium carbonate and gypsum, these critical values are approximately 2.5 and 1.3 to 1.4, respectively. Above the critical value, nucleation begins to predominate. Processes that operate in the nucleation region tend to have scaling problems, whereas, processes that operate below the critical relative saturation value may be scale-free. A conservative process would maintain the relative saturation at levels less than or equal to 1.0.

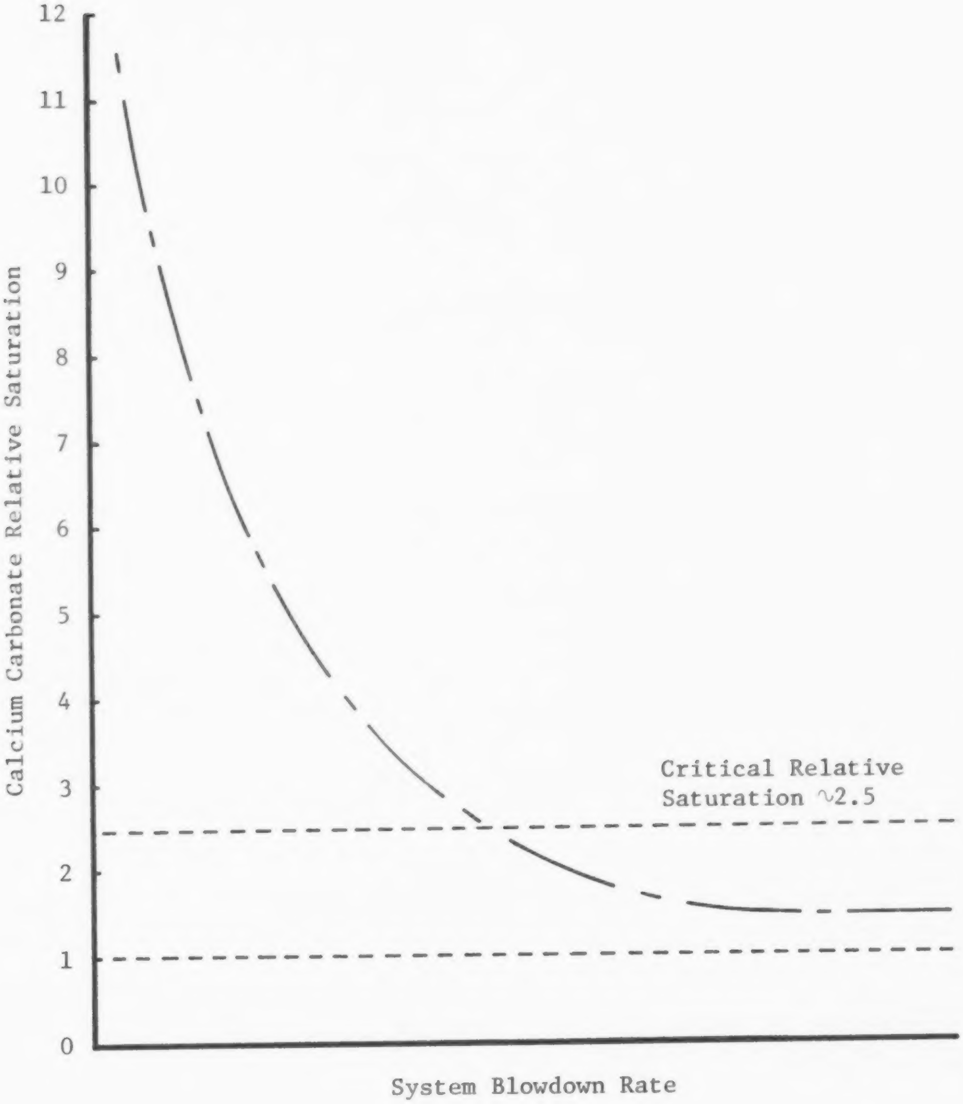

Figure 3-2. Potential reduction in $CaCO_3$ relative saturation resulting from solids formation in the system.

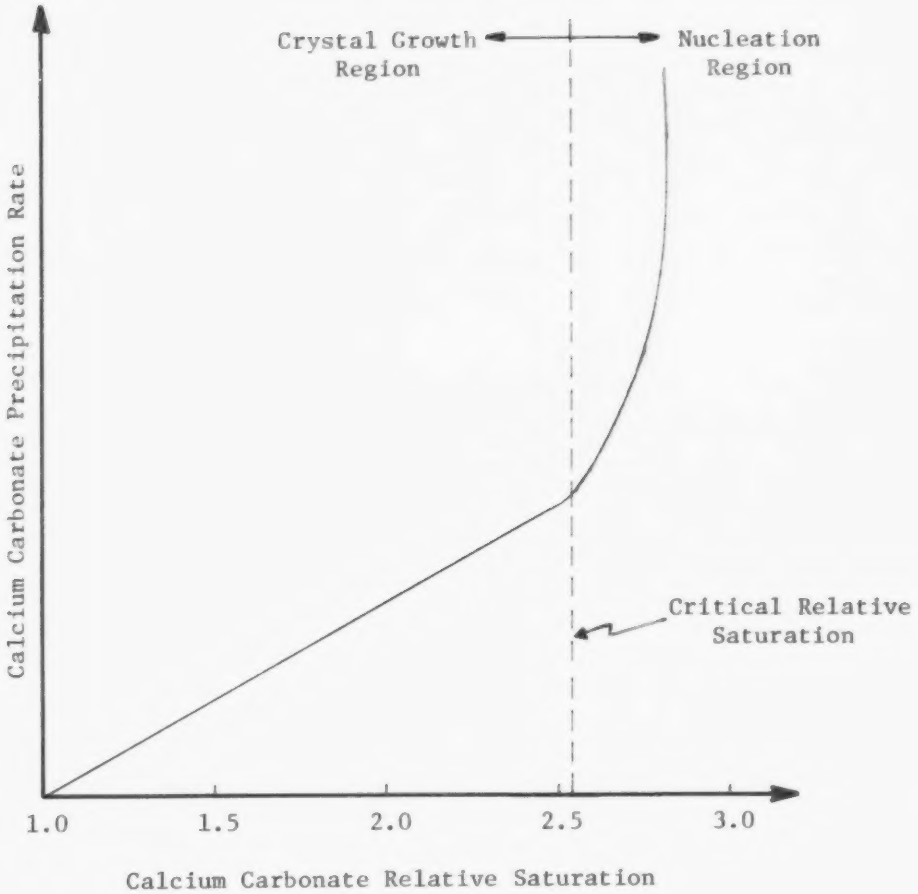

Figure 3-3. Calcium carbonate precipitation as a function of relative saturation.

The blowdown for the pilot unit will be set slightly higher (20%) than the predicted minimum blowdown achievable. Sampling and analysis to monitor for steady-state operation will follow the procedure discussed in Section 3.1. When the pilot unit is operating at steady-state, a complete set of system characterization samples will be taken at each major sample point listed in Table 3-2. The ultrasonic scale detector will be read and the test loop will be disassembled for visual inspection.

3.3 FIELD TEST FOR MINIMUM BLOWDOWN WITH ADDITIONAL ASH MIXING TIME

The purpose of this field test is to evaluate the use of a reaction tank for providing additional ash mixing time as a means of promoting precipitation prior to sluicing and consequently controlling scale in the sluice line. As previously described in Section 3.2, calcium carbonate precipitation may occur in the sluice line or filter press because of calcium leached from the fly ash. The amounts of soluble species which are leached from ash is to some degree a function of the contact time between the ash and the sluice water. By increasing the contact time, a greater amount of ash leaching can be attained. In turn, the high levels of dissolved species may cause the critical relative saturation values to be exceeded (see Figure 3-3), such that solids precipitation occurs in the reaction tank instead of in the sluice line. A longer ash/water contact time prior to sluicing provides a greater possibility for solids precipitation and subsequent "desupersaturation" of the sluice water, as shown in Figure 3-2.

Results from batch leaching studies performed in the lab with sample fly ash from Plant 9677 and deionized water indicate that most of the soluble species are leached in the first ten minutes of ash/water contact. These results are presented graphically in Figure 3-4. At a nominal sluice rate of 190 liters/min (50 gpm), the pilot unit has an ash/water contact time of about 8 minutes. The mixing tank provides approximately 2 minutes of contact and the filter press provides another 6 minutes. By using the reaction tank,

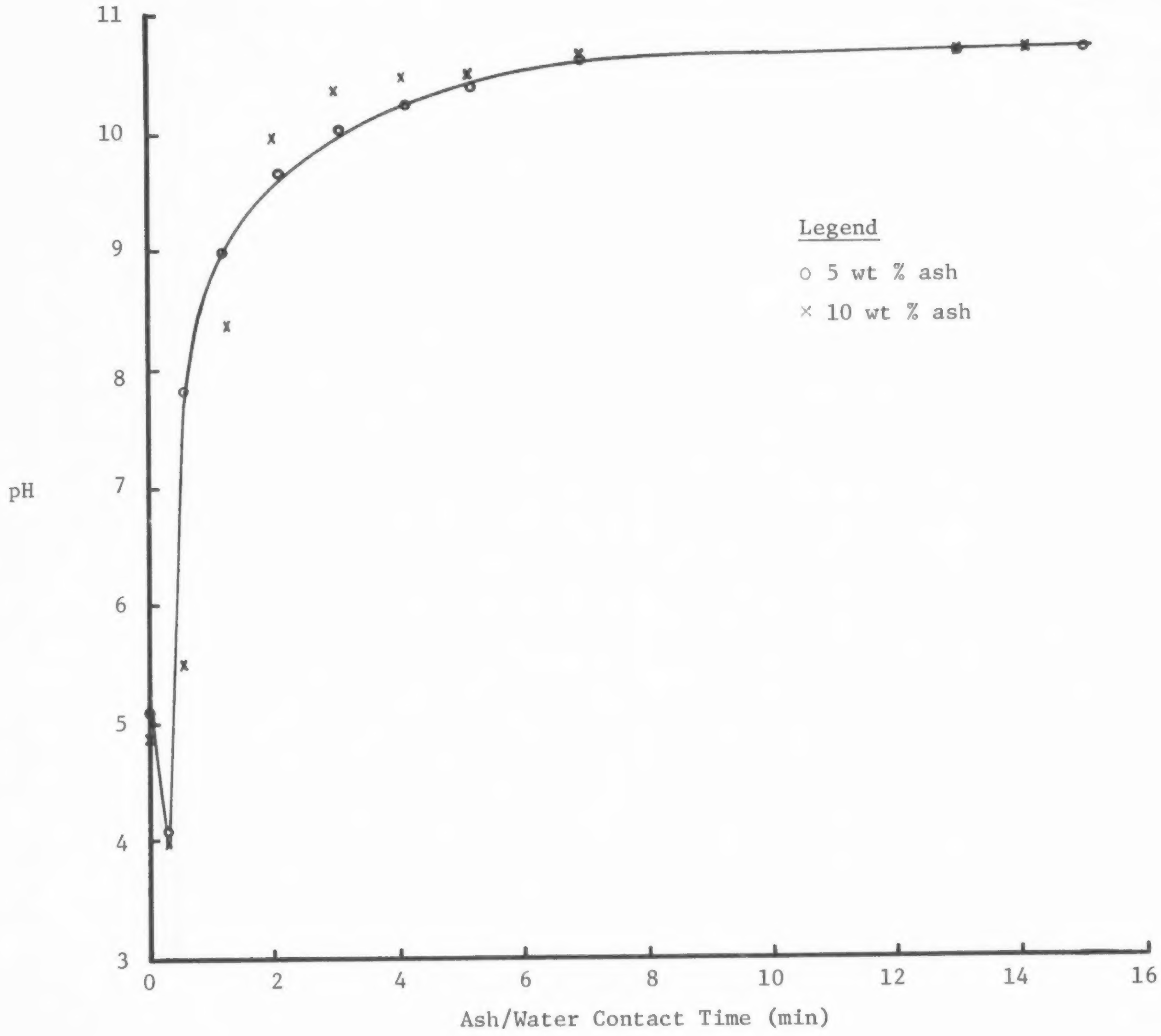

Figure 3-4. pH vs. ash/water contact time for batch fly ash lab studies.

the ash/water contact time can be increased an additional 5 to 10 minutes. Therefore, the total time of contact between the ash and water can be increased to a range of 13 to 18 minutes for a 190 liters/min (50 gpm) sluice rate.

Initially, the reaction tank will be operated with a 6 minute residence time. This will provide about 8 minutes of ash/water contact prior to sluicing, which is equivalent to the amount of contact time typically provided by the ash mix tank and the filter press. The system blowdown rate will be set at a minimum blowdown rate determined in the previous field tests (see Section 3.2). Samples will be taken as indicated in Table 3-1 every four hours. When the pilot unit is operating at steady-state, a complete set of system characterization samples will be taken at each major sample point listed in Table 3-2. The ultrasonic scale detector will be read and the test loop will be disassembled for visual inspection.

If solids precipitation occurs in the sluice line and/or filter press, the residence time in the reaction tank can be increased to 10 minutes. The total ash/water contact time prior to sluicing will then be 12 minutes. As before, steady-state operation will be monitored by taking samples every four hours as indicated in Table 3-1. A complete set of system characterization samples will be taken when the pilot unit is operating at steady-state. The ultrasonic scale detector will be read and the test loop will be disassembled for visual inspection.

Although the ash mixing tank and the reaction tank have maximum residence times of 2 and 10 minutes, respectively, the residence times of these equipment can be increased by operating the pilot unit at a slurry flow rate less than the design maximum of 190 liters/min (50 gpm). Therefore, if solids precipitation occurs in the sluice line or filter press even when the reaction tank is operating at the design maximum, the residence time in the reaction tank can be further increased by reducing the pilot unit sluice rate.

3.4 FIELD TEST FOR MINIMUM BLOWDOWN AND CHEMICAL TREATMENT

The purpose of these tests is to determine the minimum blowdown rate achievable by using chemical treatment of the recycle water. As discussed in the previous sections, the anticipated calcium carbonate relative saturation levels of the recycle water indicate a significant potential for $CaCO_3$ precipitation in the recycle line. A common method for reducing the potential for $CaCO_3$ precipitation is pH adjustment by sulfuric acid (H_2SO_4) addition. However, the addition of H_2SO_4 causes an increase in the aqueous sulfate level, which may lead to gypsum ($CaSO_4 \cdot 2H_2O$) precipitation. Therefore, the amount of sulfuric acid which can be added for pH adjustment must be closely monitored to avoid gypsum scaling.

Using ash leaching data obtained from lab studies on sample fly ash from Plant 9677, a series of computer simulation cases was completed to determine the acid addition rate required to prevent $CaCO_3$ scale formation in the recycle line for various blowdown rates. These simulations also calculated the potential for gypsum scaling in the recycle line. All cases were based on a slurry containing 1.0 weight percent ash and assumed no solid formation at any point in the system. The results are presented in Table 3-3.

These results indicate that when sulfuric acid addition is used for pH adjustment, the minimum blowdown achievable is between 1.0 and 3.0 gpm. For a blowdown rate in this range, it is possible to control $CaCO_3$ scale potential by increasing the sulfuric acid addition rate. However, the resulting increase in the aqueous sulfate concentration causes the potential for gypsum scaling to become the limiting factor in determining the minimum blowdown rate.

These results also indicate a significant potential for $CaCO_3$ precipitation in the reaction tank and/or filter press. These results agree with earlier computer simulation results which indicate that some $CaCO_3$ precipitation will occur in the sluice line and/or filter press. These $CaCO_3$

TABLE 3-3. ESTIMATED SCALING POTENTIAL FOR PILOT UNIT OPERATION WITH CHEMICAL TREATMENT

Blowdown Rate (gpm)	Acid Addition Rate[1] (gpm)	Mixing Tank Effluent			System Blowdown		
		pH	RS $CaCO_3$	RS Gypsum	pH	RS $CaCO_3$	RS Gypsum
0.0	0.001	9.9	94.92	6.94	7.0	1.17	6.99
1.0	0.001	10.0	90.07	2.31	7.2	0.78	2.36
3.0	0.001	10.1	84.34	0.86	7.4	0.86	0.90
5.0	0.001	10.2	78.97	0.48	7.4	0.69	0.52
7.0	0.001	10.2	75.42	0.31	7.6	0.94	0.35
10.0	0.001	10.2	69.91	0.19	7.6	0.78	0.22
15.0	0.001	10.3	63.17	0.10	7.8	0.99	0.13

[1] 98 wt. % H_2SO_4

RS = Relative Saturation

solids will be removed with the ash in the filter press and will effectively reduce the aqueous calcium concentration in the recycle water. The lower calcium carbonate relative saturation will mean a lower sulfuric acid addition rate and consequently a lower potential for gypsum precipitation in the recycle line. Therefore, depending on the amount of calcium carbonate removed in the filter press, it may be possible to operate the pilot unit at a considerably lower blowdown rate than predicted in Table 3-3.

Data from the previously completed field tests will be used to estimate the amount of $CaCO_3$ precipitation in the sluice line and/or filter press. Based on this estimated $CaCO_3$ precipitation, an approach to solid-liquid equilibrium will be used to complete a revised set of computer simulation cases. The pilot unit will be operated at a blowdown rate slightly higher (20%) than the minimum blowdown predicted by the computer model. The pilot unit will be monitored for steady-state operation by sampling every four hours according to Table 3-1. When the pilot unit is operating at steady-state, a complete set of system characterization samples will be taken at each major sample point listed in 3-2. The ultrasonic scale detector will be read and the test loop will be disassembled for visual inspection.

If aqueous concentrations predicted by the computer model are in close agreement with field test results, the blowdown rate for the pilot unit will be set at the minimum blowdown calculated by the computer model. If there is disagreement between the computer model and the field test results, a new set of simulation cases will be completed based on the current field test data to determine a new estimate for the minimum blowdown achievable. The pilot unit will be monitored for steady-state operation at minimum blowdown by sampling every four hours according to Table 3-1. When the pilot unit is operating at steady state, a complete set of system characterization samples will be taken from the sample points listed in Table 3-2. The ultrasonic scale detector will be read and the test loop will be disassembled for visual inspection.

3.5 FIELD TEST FOR MINIMUM BLOWDOWN WITH CHEMICAL TREATMENT AND SIDESTREAM SOFTENING

The purpose of these tests is to determine the minimum blowdown rate achievable by using a combination of chemical treatment (acid addition) and sidestream softening to control scaling potential in the recycle line. Depending on the success of acid addition for scale prevention experienced in the previous field tests, sidestream softening may not be required. That is to say, if the pilot unit can be operated at zero blowdown without scale formation when using chemical treatment only, then sidstream softening for calcium removal is not necessary. However, if zero blowdown has not yet been achieved, then the blowdown rate can be further reduced by softening a portion or all of the recycle water.

A common method of controlling gypsum scale formation is to reduce the aqueous calcium concentration by precipitating calcium carbonate in a lime-soda ash softener. Lime ($Ca(OH)_2$) is added to increase the pH of the water causing a bicarbonate (HCO_3^-) to carbonate ($CO_3^{=+}$) ion shift according to the following reaction:

$$Ca(OH)_2 + 2HCO_3^- \quad Ca^{++} + 2CO_3^{=} + 2H_2O \qquad (3-1)$$

When enough carbonate becomes available, the calcium is removed from the aqueous phase as calcium carbonate ($CaCO_3$) precipitate. If the system is carbonate deficient, supplementary carbonate can be added in the form of soda ash (Na_2CO_3).

For a sidestream softening operation, a small portion of the pond recycle water is pH adjusted with lime and soda ash (if necessary) to lower the aqueous calcium concentration to about 30-50 ppm. The softened water is then blended with the untreated recycle water to thereby lower the overall aqueous calcium concentration of the return water and control gypsum scaling.

As in prior field tests, a series of computer simulation cases will be completed to estimate the minimum blowdown achievable for a system using acid addition and sidestream softening. The results of these simulation cases will also provide pilot unit operating conditions for sidestream treatment rate, softener chemical addition rate, and adjusted pH level of the recycle water. These simulation cases will be based primarily on the results from previous field tests.

Based on the operating conditions predicted by the computer model, the pilot unit will be operated at a blowdown rate slightly higher (20%) than the predicted minimum blowdown achievable. Steady state will be monitored according to the sampling and analysis strategy outlined in Table 3-1. When the pilot unit is operating at steady state, a complete set of system characterization samples will be taken. The ultrasonic scale detector will be read and the test loop will be disassembled for inspection.

Based on the agreement between the computer model results and the field test results, the pilot unit will be operated at a revised minimum blowdown rate. This estimated blowdown rate will be based on all the field test data and may represent the absolute minimum blowdown rate at which the pilot unit can operate without scale formation in the recycle line. The pilot unit will be monitored as before and a complete set of system characterization samples will be taken when the pilot unit is operating at steady state. The ultrasonic scale detector will be read and the test loop will be disassembled for visual inspection.

3.6 DATA CATALOGUING PROCEDURES

Operating the pilot unit under a number of conditions will produce a significant amount of process and analytical data which must be properly recorded. Therefore, a procedure for data cataloguing will be established. This procedure is based on three identification numbers:

- Plant ID,
- Field Test ID, and
- Sample ID.

The Plant ID denotes the test site; for this site, the Plant ID is 9677. The Field Test ID indicates the type of water treatment process in operation and the weight percent ash in the slurry. The Sample ID denotes the sample point location as given in Table 3-2.

3.6.1 Field Test Identification

The Field Test ID consists of two parts. The first part indicates the type of water treatment being used according to the following code:

- 1 - no treatment,
- 2 - additional ash mixing time prior to sluicing,
- 3 - acid treatment, and
- 4 - acid treatment and sidestream softening.

The second part of the Field Test ID denotes the amount of ash in the slurry according to the following code:

- A - 1.0 wt. %,
- B - 5.0 wt. %, and
- C - 10.0 wt. %.

Therefore, if the Field Test ID was 3-B, the pilot unit would be sluicing 5.0 weight percent ash and would be using sulfuric acid addition to control calcium carbonate precipitation.

3.6.2 Sample Labels

Each sample will be labeled with the Plant ID, Field Test ID, Sample ID, date, time, and type of analysis to be performed. An example label is shown in Figure 3-5.

3.6.3 Log Sheets for Monitoring Steady-State Operation

A list of samples and operating parameters to monitor for steady-state operation are presented in Table 3-1. Samples for all tests will be taken every four hours. The appropriate process data and analytical results will be recorded on log sheets as shown in Figure 3-6. These log sheets will provide a complete account of the parameters important for determining steady-state operation.

3.6.4 Analytical Data Sheets for System Characterization Samples

Whenever a sample is completely analyzed for anions, cations and carbonate, the results will be listed on an analytical data sheet as shown in Figure 3-7. These data will be used to completely characterize the pilot unit when operating at steady-state conditions. Other data, such as ionic strength, relative saturation values and the residual electroneutrality (ion charge imbalance) will be calculated by the computer model. These data sheets will provide the basis for model verification and/or modification.

3.6.5 Process Data Sheets for System Characterization

Whenever a set of system characterization samples is taken, it is also necessary to record the appropriate process operating data. These data, which consist primarily of flow rates, pH levels and solids levels, will be recorded on a master process data sheet for each plant as shown in Figure 3-8. These process operating data are essential to the interpretation of analytical sample data for the pilot unit.

PLANT ID ____________________

FIELD TEST ID _________________

SAMPLE POINT ID _______________

DATE __________________________

TIME __________________________

ANALYSIS[1] _____________________

[1] AN = Anions
CAT = Cations
CARB = Carbonate
TM = Trace Metals

Figure 3-5. Sample Label.

PLANT ID ________ FIELD TEST ID ________

Date MMDD	HHMM	SYSTEM BLOWDOWN			MIX TANK/REACTION TANK EFFLUENT			MAKEUP WATER	RECYCLE WATER		SOFTENER FEED		SOFTENER BLOWDOWN			SOFTENER CHEMICALS		
		Ca (ppm)	Na (ppm)	Flow Rate (gpm) *	Ca (ppm)	Na (ppm)	pH	Flow Rate (gpm)	pH	Flow Rate (gpm)	Ca (ppm)	Flow Rate (gpm)	Ca (ppm)	Na (ppm)	Flow Rate (gpm)	Lime Flow Rate (gpm)	Ash Flow Rate (gpm)	COMMENTS

*Instrumentation for the field test unit provides data in English units.

Figure 3-6. Log sheets for steady-state operation.

PLANT ID _______ FIELD TEST ID _______

Radian #	Sample Location	Date	Time	Test #	Sample #	pH	Temp.	TSS	wt.%	Total Hardness	Ca	Mg	Na	K
		MMDD	HHMM	--	--	--	°C	mg/1	%	mg/1 as $CaCO_3$	mg/1	mg/1	mg/1	mg/1

Figure 3-7. Liquid phase analysis summary.

PLANT ID ______ FIELD TEST ID ______

Radian #	P Alk	M Alk	Free CO_2	Cl	SO_4	NO_3	Si	Al	NH_3	COMMENTS
	mg/l as $CaCO_3$	mg/l as $CaCO_3$	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	

Figure 3-7. Liquid phase analysis summary. (continued)

PLANT ID ____________

	FIELD TEST ID					
Date/Time (MMDD/HHMM)						
Makeup Feed Rate (gal/min)*						
Ash Feed Rate (lb/hr)						
Wt % Solids in Slurry (%)						
Blowdown Rate (gal/min)						
Reaction Tank Residence Time (min)						
Filter Press Blowdown Rate (gal/min)						
Filter Press Wt % Solids (%)						
Recirculating Water pH						
Acid Addition Rate (gal/min)						
Sidestream Treatment Rate (gal/min)						
Softener Blowdown Rate (gal/min)						
Softener Wt % Solids (%)						
Lime Addition Rate (lb/hr)						
Soda Ash Addition Rate (lb/hr)						
MgO Addition Rate						

*Instrumentation for the field test unit provides data in English units.

Figure 3-8. Process data sheets.

SECTION 4

ANALYTICAL METHODS

Several different types of analytical methods will be required for the field test activities outlined in Section 3. A general description of the analytical methods and procedures is presented in this section. These methods include:

- pH and temperature (when not automatically monitored by test unit instrumentation),
- total suspended solids (TSS),
- total dissolved solids (TDS),
- specific gravity,
- atomic absorption (for Ca, Mg, Na, and K),
- ion chromatography (for Cl, NO_3, and SO_4), and
- non-dispersive infrared (for carbonate).

A general discussion of the analytical test methods is presented in the following subsections.

4.1 pH AND TEMPERATURE

Temperature and pH measurements will be made on the raw, unfiltered samples at the sampling location. This will require a portable pH meter and a thermometer which is not easily broken. The measurements normally can be made while the sampling line is being purged before other collection procedures.

4.1.1 Apparatus

- Portable electronic pH meter with temperature compensation adjustment;
- glass electrode;
- calomel or silver-silver chloride reference electrode; {or combination pH electrode}
- buffer solutions of known pH for standardization of pH meter (pH 4 and 7); and
- heavy duty thermometers, °F and °C scales.

4.1.2 Procedure

Because of the differences between the many makes and models of commercially available pH meters, it is impossible to provide detailed instructions for the proper operation of every instrument. In each case, follow the manufacturer's instructions. Thoroughly wet the glass and reference electrodes by immersing the tips in water overnight or in accordance with instructions. Thereafter, when the meter is not in use, keep the tips of the electrodes immersed in water.

Before use, remove the electrodes from the water and rinse with distilled or demineralized water. Dry the electrodes by gentle wiping with a soft tissue. Standardize the instrument with the electrodes immersed in a buffer solution with a pH near that of the sample to be analyzed. Be sure that the temperature dial on the pH meter has been set to the temperature of the solution being measured. Remove the electrodes from the buffer, rinse thoroughly, and wipe clean. Immerse in a second buffer approximately 4 pH units different from the first and note the pH reading; the reading should be within 0.1 unit of the pH for the second buffer.

Rinse electrodes thoroughly, wipe, and immerse in the sample. Agitate the sample sufficiently to provide homogeneity and keep solids in suspension. If the sample temperature is different from that of the buffers, let the electrodes equilibrate with the sample. Measure the sample temperature and set the temperature compensator on the pH meter to the measured temperature. Note and record the pH and temperature. Rinse electrodes and immerse in water until the next measurement.

When only occasional pH measurements are made, standardize the instrument before each measurement. Where frequent measurements are made, intermittent standardization (every one hour or two hours) is satisfactory. However, if sample pH values vary widely, standardize more frequently with buffers whose pH's bracket the range encountered for the sample. Measure with two or more buffers of different pH at least once daily and more frequently if samples contain abrasive solids or dissolved fluorides in order to check the linearity of response. When electrode response to two buffers 4 pH units different shows differences greater than 0.1 pH unit, replacement of the glass electrode is usually necessary.

4.1.3 Precision and Accuracy

The precision and accuracy attainable with a given pH meter will depend on the type and condition of the instrument and the care used in standardization and operation. Guard against possible erratic results arising from mechanical or electrical failures - weak batteries, damaged electrodes, improper grounding, plugged liquid junctions, and fouling of the electrodes with oily or precipitated materials. With proper care, a precision of ±0.02 pH unit and an accuracy of ±0.05 pH unit can be achieved with many of the new models. However, ±0.1 pH unit represents the limit of accuracy under normal conditions. For this reason, report pH values only to the nearest 0.1 pH unit.

4.2 TOTAL SUSPENDED SOLIDS (TSS)

The suspended matter is retained on a filter disk after filtration of a known weight of slurry. The residue is dried and weighed. Two cases are presented:

- samples high in solids content ≥0.5%; and
- samples low in solids content <0.5%.

4.2.1 Apparatus

- Drying oven equipped with a thermostatic control;
- desiccator with indicating desiccant;
- balance:
  - -- high TSS - top loader 0.1 or 0.01 gram accuracy,
  - -- low TSS - analytical balance 0.1 mg accuracy;
- filter disks:
  - -- high TSS - 70 mm Whatman #2,
  - -- low TSS - 47 mm Millipore AAWP (0.8 μm pore size);
- filtration apparatus:
  - -- high TSS - 70 mm Buchner funnel,
  - -- low TSS - 47 mm Millipore filter holder,
  - -- suction flask, 500 ml,
  - -- aspirator or vacuum pump,
  - -- vacuum tubing (100 cm),
  - -- watch glass.

4.2.2 Procedure

- High Suspended Solids Case

  Preparation of Filter - Dry the 70 mm filter paper in an oven at 105°C for at least one-half hour. Weigh immediately before use to 0.01 gram (or 0.1 g depending on balance) accuracy. Record the filter weight.

  Sample Treatment - Weigh the bottle (with lid) and contents to 0.01 (or 0.1 g depending on balance) accuracy and record in notebook as sample plus bottle weight. Under suction, filter the entire contents of the bottle. Subtract the empty bottle weight. The difference is the sample weight. (Note: At this point, if analyses are desired on the filtrate, such as TDS, relieve the suction and pour the filtrate into a clean, labeled polyethylene bottle.) Rinse all solids out of the bottle and onto the filter with deionized water. Rinse the filter cake and filter with acetone (this will speed drying). Carefully remove the filter from the funnel, place it on a watch glass, and put in the oven at 105°C. Dry for at least one hour, cool in a desiccator, and weigh the filter and the dried solids. Repeat the drying cycle until a constant weight is obtained or until the weight loss is less than 0.05 gram.

- Low Suspended Solids Case

  Basically, the same procedure is followed as in the first case except: (1) Use a 47 mm cellulose acetate filter membrane (#0047 AAWP, 0.8 micron, Millipore Corp.); (2) dry at 50-60°C; and (3) do not use acetone to rinse the solids on the filter. Use an analytical balance to weigh the filter and filter plus residue to 0.1 mg accuracy.

4.3 TOTAL DISSOLVED SOLIDS (TDS)

Total Dissolved Solids (TDS) are materials that pass through a glass fiber filter disk and remain after evaporation and drying to a constant weight a 105°C. The filtrate from the weight % solids determination may be used to determine TDS, if it has not been contaminated or diluted.

4.3.1 Apparatus

- All of the apparatus required in Section 4.2.1 (weight % solids) is required plus the following:

  -- evaporating dish, 100 ml capacity, porcelain (100 ml beakers can be substituted); and

  -- hot plate or steam bath.

4.3.2 Procedure

- Preparation of Evaporating Dish - Place the dish in an oven kept at 103-105°C for at least one-half hour. Remove and cool in a desiccator. Weigh the dish immediately after removal from the desiccator and record the weight to 0.1 mg.

- Sample Analysis - Because excessive residue in the evaporating dish may form a water-entrapping-crust, use a sample volume that yields no more than 500 mg of residue. Transfer a suitable but accurately measured (volumetric to deliver pipet) volume of the filtered sample to the weighed evaporating dish. Evaporate to 10-20 ml on a hot plate (avoid boiling) or to dryness on a steam both. Dry in an oven at 105 ±5°C for at least one hour, cool in a desiccator, and weigh to 0.1 mg. Repeat the drying cycle until a constant weight is obtained (i.e., the weight loss between consecutive weighings is less than 0.5 mg).

- Calculation -

  $$\text{g/l of TDS} = \frac{(A - B) \times 1000}{C}$$

  where A = weight of residue + dish (g),
  B = weight of dish only (g), and
  C = ml of sample used.

- Interferences - Highly mineralized waters with a considerable calcium, chloride, magnesium, and/or sulfate content may be hygroscopic and require prolonged drying, proper desiccation, and rapid weighing.

4.4 SPECIFIC GRAVITY

Specific gravity is determined by comparing the weight of a volume of the sample with that of an equal volume of distilled water.

4.4.1 Apparatus

- Specific gravity bottles - 25 ml capacity,
- analytic balance - 0.1 mg accuracy.

4.4.2 Procedure

- Weigh to the nearest milligram an empty specific gravity bottle of about 25 ml capacity. Fill completely with distilled water which is at room temperature and weigh again. Empty and fill the bottle completely with the sample (at room temperature) and reweigh.

4.4.3 Calculation

$$\text{Specific gravity} = \frac{(A-B)}{(C-B)}$$

where A = weight of sample + bottle,
B = weight of empty bottle, and
C = weight of bottle + water.

4.5 ATOMIC ABSORPTION

Atomic absorption involves aspirating a liquid sample into an air-acetylene flame where it is vaporized and atomized. Radiation from an appropriate hollow cathode lamp is passed through the flame. Radiation passes through a monochromator, to a detector, and finally to a digital readout or strip chart recorder. The output for unknown samples is compared to standards of known concentration to obtain sample concentrations. Interferences in the calcium and magnesium determinations are masked by diluting the sample with a lanthanum chloride solution.

Analytical parameters for the determination of calcium, magnesium, sodium, and potassium are listed in Table 4-1.

TABLE 4-1. ANALYTICAL PARAMETERS FOR AA ANALYSES

Element	Wavelength (nm)	Detection Limit (g/ml)	Upper Limit of Range (g/ml)
Ca	422.7	0.1	4.0
Mg	285.2	0.01	0.4
Na	589.6	0.05	1.0
K	766.5	0.01	2.0

4.5.1 Apparatus

- Perkin Elmer Model 403 Atomic Absorption Spectrophotometer (AA);
- appropriate Ca, Mg, and Na hollow cathode lamps;
- cylinder of acetylene gas;
- air supply; and
- volumetric glassware for preparing standards and diluting samples.

4.5.2 Reagents

1% $LaCl_3 \cdot 7H_2O$

- Weigh out 101.6 g $LaCl_3 \cdot 7H_2O$.
- Dissolve with deionized water in a 4-liter eluent bag.
- Add 200 ml concentrated HCl.
- Dilute to 4 liters and shake well.

4.5.3 General Operating Procedure

- Turn power on.
- Insert appropriate lamp, set lamp current and let the instrument warm up for at least one-half hour.
- Set instrument parameters (slit, filter, etc.) according to the specifications in the instrument manual.
- Align burner head.
- Increase gain control to mid-range.
- Set wavelength for element of interest and maximize energy output (also set to visible or UV region).
- Align the lamp to maximize the energy output.
- Adjust gain to set needle in the middle of the dark red area.
- Open acetylene tank and make sure there is a sufficient air supply. Set air flow to 60 (top of red ball) and acetylene to 30. Check flow before each operation of the instrument.
- With aspirator in deionized water, push ignite button to ignite flame. Make sure the vent hood is turned on.
- Push auto zero button and wait for it to stabilize.

4.5.4 Sample Analysis

- For Ca or Mg analysis, the "moustache" attachment is used to aspirate samples with $LaCl_3$ into the flame. It is very important that the sample and lanthanum solution levels be the same when aspirating with the moustache. For Na and K analysis this is not used.
- Aspirate standards into the flame and determine if they are in a linear relationship.
- Aspirate a sample and watch digital output to make sure the sample is in the same concentration range as the standards.
- Aspirate deionized water as needed to check the instrument zero.
- Allow the digital readout to register four or five readings, take an average value and record in the AA notebook.

4.5.5 AA Shutdown

- Aspirate deionized water into the flame to clear out the system for about 5 minutes.
- Push button to shut off gas supply and turn off the flame.
- Shut acetylene tank off.
- Turn down gain control all the way.
- Turn off lamp current.
- Turn off power.

4.5.6 Calculations

- The digital readouts are directly proportional to the cation concentration of the sample.
- On linear graph paper draw a graph of concentration versus readout for the standards. The plot should be linear.
- Calculate the sample concentrations by comparing their readouts to the calibration curve.
- Multiply by the dilution factor and any AA dilution to get the final sample concentration in parts per million which is converted to millimoles per liter using the atomic weight of the element.

4.5.7 Determination of Calcium (Ca)

Recommended concentrations for calcium standards are 2.0 and 4.0 ppm. A blank of deionized water is also used for 0.0 ppm. Calcium standards are usually stable, but due to contamination from aspiration into the instrument, they need to be prepared twice a week. They may be mixed with most other standards.

Obtain a Fisher Scientific certified calcium AA standard of 1000 ppm.

- 4.0 ppm Ca

  Pipet exactly 4.0 ml of the 1000 ppm calcium standard into a 1-liter volumetric flask and dilute to volume with deionized water. Store in a 250-ml polyethylene bottle with appropriate label and date.

- 2.0 ppm Ca

  Pipet exactly 2.0 ml of the 1000 ppm calcium standard into a 1-liter volumetric flask and dilute to volume with deionized water. Store in a 250-ml polyethylene bottle with appropriate label and date.

4.5.8 Determination of Magnesium (Mg)

Recommended concentrations for magnesium standards are 0.2 and 0.4 ppm. A blank of deionized water is also used for 0.0 ppm. A stock solution (100 ppm) is prepared from a certified AA standard. Dilute standards are then prepared from the stock solution. Magnesium standards are usually stable, but due to contamination from aspiration into the instrument, they need to be prepared twice a week. They may be mixed with most other standards.

- Stock Magnesium Solution (100 ppm)

  Obtain a Fisher Scientific certified magnesium AA standard of 1000 ppm. To prepare the stock solution pipet exactly 25.00 ml of the 1000 ppm solution into a 250-ml volumetric flask and dilute to volume with deionized water. Store in a polyethylene bottle with appropriate label and date.

- 0.4 ppm Mg

  Pipet exactly 4.0 ml of the 100 ppm magnesium stock solution into a 1-liter volumetric flask and dilute to volume with deionized water. Store in a 250-ml polyethylene bottle with approprite label and date.

- 0.2 ppm Mg

  Pipet exactly 2.0 ml of the 100 ppm magnesium stock solution into a 1-liter volumetric flask and dilute to volume with deionized water. Store in a 250-ml polyethylene bottle with appropriate label and date.

4.5.9 Determination of Potassium (K)

Recommended concentrations for potassium standards are 1.0 and 2.0 ppm. A blank of deionized water is also used for 0.0 ppm. A stock solution (100 ppm) is prepared from a certified AA standard. Dilute standards are then prepared from the stock solution. Potassium standards are usually stable, but due to contamination from aspiration into the instrument, they need to be prepared twice a week. They may be mixed with most other standards.

- Stock Potassium Solution (100 ppm)

  Obtain a Fisher Scientific certified potassium AA standard of 1000 ppm. To prepare the stock solution pipet exactly 25.00 ml of the 1000 ppm solution into a 250-ml volumetric flask and dilute to volume with deionized water. Store in a polyethylene bottle with appropriate label and date.

- 2.0 ppm K

  Pipet exactly 2.0 ml of the 100 ppm potassium stock solution into a 1-liter volumetric flask and dilute to volume with deionized water. Store in a 250-ml polyethylene bottle with appropriate label and date.

- 1.0 ppm K

  Pipet exactly 1.0 ml of the 100 ppm potassium stock solution into a 1-liter volumetric flask and dilute to volume with deionized water. Store in a 250-ml polyethylene bottle with appropriate label and date.

4.5.10 Determination of Sodium (Na)

Recommended concentrations for sodium standards are 0.5 and 1.0 ppm. A blank of deionized water is also used for 0.0 ppm. A stock solution (100 ppm) is prepared from a certified AA standard. Dilute standards are then prepared from the stock solution. Sodium standards are usually stable, but due to contamination from aspiration into the instrument, they need to be prepared twice a week. They may be mixed with most other standards.

- Stock Sodium Solution (100 ppm)

  Obtain a Fisher Scientific certified sodium AA standard of 1000 ppm. To prepare the stock solution pipet exactly 25.00 ml of the 1000 ppm solution into a 250-ml volumetric flask and dilute to volume with deionized water. Store in a polyethylene bottle with appropriate label and date.

- 1.0 ppm Na

  Pipet exactly 10.0 ml of the 100 ppm sodium stock solution into a 1-liter volumetric flask and dilute to volume with deionized water. Store in a 250-ml polyethylene bottle with appropriate label and date.

- 0.5 ppm Na

  Pipet exactly 5.0 ml of the 100 ppm sodium stock solution into a 1-liter volumetric flask and dilute to volume with deionized water. Store in a 250-ml polyethylene bottle with appropriate label and date.

4.6 ION CHROMATOGRAPHY

Ion chromatography combines the techniques of ion exchange, liquid chromatography and conductometric detection for the determination of aqueous ionic species.

A sample is injected by means of a 0.1 ml sample loop and is eluted through a system of two ion exchange columns and a conductivity cell. The first column separates the ions in the sample. Each different ion has a characteristic retention time on the column for a given set of conditions. The second column removes the eluent carrier ions thus minimizing the background conductivity of the eluent. Finally, the conductivity cell is used to determine the concentration of ions in the sample.

By comparing the sample ions retention times to known ion standards, specific ions are identified. Standard solutions with known concentrations of the ions of interest are run to obtain a calibration curve of peak height (from a strip chart recorder) versus concentration. Then the peak heights of the samples are compared to the standard curve to obtain sample concentrations.

4.6.1 Apparatus

- Dionex Model 10 or 14 Ion Chromatograph;
- strip chart recorder with input voltage settings covering the range of 0.1 to 1.0 volt;
- deionized water with conductance <5 μmhos;
- volumetric glassware for preparing standards and diluting samples;
- syringes (luer tip, 1.0 or 3.0 ml capacity); and
- rules for measuring peak heights.

4.6.2 Reagents

Stock Carbonate Solution

- Dissolve 25.45 g Na_2CO_3 in 500 ml water; and
- store in a polyethylene bottle.

Stock Bicarbonate Solution

- Dissolve 25.20 g $NaHCO_3$ in 500 ml water; and
- store in a polyethylene bottle.

Standard Anion Eluent (0.003 M $NaHCO_3$ + 0.0024 M Na_2CO_3

- Obtain a clean 4.0 l eluent bag and rinse out thoroughly;
- add 20 ml of both stock solutions to the bag;
- bring the volume in the bag up to approximtely 4 liters (allow a little air space for shaking purposes); put spout-cap on;
- shake thoroughly;
- expel air from bag; and
- if a weaker eluent is desired, add a smaller amount of stock solution to the bag; for example, adding 10 ml of each stock solution to 4 liters water would make a half strength eluent (.0015 M Na HCO_3, .0012 M Na_2CO_3).

4.6.3 General Operating Procedure

- Select proper eluent and column depending on which anions are to be analyzed and proceed with the following instructions.
- Turn air on (∿80 psi, dry).
- Turn power on.
- Start eluent pump at ∿30% flow rate.
- Switch columns in line.
- Check pressure; if more than 700 psi, reduce the flow rate.
- If pressure is unusually low, disconnect outlet line from the pump to allow air bubbles to escape.
- Let system run about 10 minutes.
- Begin by setting full-scale on conductance meter to 30 μmho's.

- Turn mode switch to linear.
- Set conductance to zero using the offset control.
- Turn on the recorder.
- Set input voltage to .5 volt; chart speed at 0.5 cm/min (or 30 cm/hr).
- Adjust zero point on the recorder to about 5% of full scale.
- Watch recorder trace for a stable baseline.
- Reset the offset control if necessary.
- When baseline is stable, analyses can begin.

4.6.4 Sample Analysis

- Set the inject/load switch to load.
- With a 1.0 ml syringe, flush the sample loop by injecting 3 portions of the highest concentration standard. Note: See the determination procedure for each species for standard preparation.
- Flip the switch to the inject mode and press the red pip button to mark the injection point on the chart paper.
- After a minute or two, flip the injection switch back to the load position.
- Watch the recorder trace, noting the retention time of the peaks and the height of the peaks.
- If the peak is less than 1/2 of the chart paper in height, switch the recorder to 0.2 mv input; if the peak is off-scale, switch the input voltage to one volt. Some recorders have a fine adjustment control which allows the peak height to be adjusted more precisely. 75% of the chart height is a good height for the high standard.
- Run the other standards by repeating steps 1-5. A nearly linear relationship of concentration vs. peak height should be obtained.

- Samples should be free of any suspended solids. Filter them if there is any doubt (syringe-tip filter is commonly used).
- If necessary, dilute the sample so that it is in the same concentration range as the standards.
- When analyzing samples, wait until all peaks have eluted before injecting the next sample.
- Run standards as needed. Usually every 10 samples or so.
- Write the sample number or standard identification and dilution factor on the strip chart by the pip mark.

4.6.5 Dionex Shutdown

- Switch eluent to water. Turn mode switch to zero.
- Run water through the system for about 10 minutes.
- Bypass both columns (switches down).
- Turn eluent pump off.
- If the unit has been run for 8-10 hours, it should be regenerated.

Regeneration of Suppressor Column

- The column is regenerated by backflushing it with 1.0 N H_2SO_4 and rinsing with water.
- Make up the regenerant solution: 111.0 ml of commercial concentrated H_2SO_4 per 4.0 liters of deionized water.
- Set regeneration time at 15 minutes and rinse time at 25 minutes.
- Press the green button labeled start. The instrument will run through the regeneration cycle and turn itself off. The air must be left on for the duration of the regeneration cycle.

4.6.6 Peak Measurement and Calculation

- Peak heights are directly proportional to the anion concentration in the sample.
- Peaks are measured from a line drawn tangent to the baseline to the tip of the peak.
- On linear graph paper draw a graph of concentration versus peak height of the standards. The plot should be linear.
- Calculate the sample concentrations by comparing their peak heights to the calibration curve.
- Multiply by the dilution factor to get the final sample concentration in millimoles per liter.

4.6.7 Determination of Chloride (Cl^-)

Recommended concentrations for chloride standards are 0.1, 0.2, 0.3, and 0.4 millimoles/liter. A stock solution (10 mM) is prepared from HCl analytical concentrate or from crystalline NaCl. Dilute standards are then prepared from the stock solution. Chloride standards are usually stable for several months and may be mixed with most other standards.

- Stock Chloride Solution (10 mM) from Analytical Concentrate

  Obtain an HCl analytical concentrate which will make 1 liter of 1.0 M HCl (J. T. Baker Chemical Co., DILUT-IT, 1N HCl, #4657). Prepare the solution following the instructions on the container. To make the 10 mM stock solution, pipet exactly 5.00 ml of the 1.0 M solution into a 500 ml volumetric flask and dilute to volume with deionized water. Store in a polyethylene bottle with appropriate label and date. If convenient, stopper and store remaining 1.0 M HCl solution for future use; it is very stable.

- Stock Chloride Solution (10 mM) from Sodium Chloride

  Weigh 0.5845 grams of dried (105°C) reagent grade NaCl on an analytical balance. Transfer to a 1.0 liter volumetric flask and dilute to volume with deionized water. This solution is 10 mM chloride. Store in a polyethylene bottle with an appropriate label and date.

- 0.4 mM Cl^-

  Pipet exactly 10.00 ml of the 10 mM chloride solution into a 250 ml volumetric flask and dilute to volume with deionized water. Store in a 250 ml polyethylene bottle with approprite label and date.

- 0.3 mM Cl^-

  Pipet exactly 15.0 ml of the 10 mM chloride solution into a 500 ml volumetric flask and dilute to volume with deionized water. Store in a polyethylene bottle with appropriate label and date.

- 0.2 mM Cl^-

  Pipet exactly 5.0 ml of the 10 mM chloride solution into a 250 ml volumetric flask and dilute to volume with deionized water. Store in a polyethylene bottle with appropriate label and date.

- 0.1 mM Cl^-

  Pipet exactly 5.00 ml of the 10 mM chloride solution into a 500 ml volumetric flask and dilute to volume with deionized water. Store in a polyethylene bottle with appropriate label and date.

4.6.7.1 Interferences--

The only interference in the measurement of chloride is fluoride. Fluoride will separate from chloride when a 500 mm separator column is used with standard eluent. If shorter columns and stronger eluents are used, they may co-elute as one peak.

4.6.7.2 Column and Eluent Conditions--

When fluoride is present and must be separated--

column : 500 x 3 mm Anion Separator Column
eluent : 0.003 M $NaHCO_3$ + 0.0024 M Na_2CO_3
flow : ∿25%
retention time : ∿2 minutes

Fluoride absent or negligible--Use conditions which optimize separation of other anions to be measured. That is, a shorter column may be more desirable.

4.6.8 Determination of Nitrate (NO_3^-)

Recommended concentrations for nitrate standards are 0.1, 0.2, and 0.3 millimole/liter. A stock solution (10 mM) is first prepared. Dilute solutions are then prepared from the stock solution. Nitrate solutions are stable and may be stored for months. They may be mixed with all other stable standards except thiosulfate.

- Stock Nitrate Solution (10 mM)

  Obtain a nitric acid analytical concentrate which will make a 0.10 N solution (J. T. Baker Chemical Co., DILUT-IT 1/10 N, #4712). Dilute to exactly 1 liter with deionized water following the instructions on the container. To make the 10 mM stock solution pipet exactly 50.00 ml of the 0.1 N solution into a 500 ml volumetric flask and dilute to volume with deionized water. Store in a polyethylene bottle with appropriate label and date.

- 0.3 mM NO_3^-

  Pipet exactly 15.00 ml of the 10 mM stock solution into a 500 ml volumetric flask and dilute to volume with deionized water. Mix well and store in a polyethylene bottle with appropriate label and date.

- 0.2 mM NO_3^-

  Pipet exactly 5.00 ml of the 10 mM stock solution into a 250 ml volumetric flask and dilute to volume with deionized water. Mix well, and store in a polyethylene bottle with appropriate label and date.

- 0.1 mM NO_3^-

  Pipet exactly 5.00 ml of the 10 mM stock solution into a 500 ml volumetric flask and dilute to volume with deionized water. Mix well, and store in a polyethylene bottle with appropriate label and date.

4.6.8.1 Interferences--

When using strong eluents and/or short columns, nitrate ion often coelutes with sulfate. This can be avoided by using standard eluent and a 500-mm column. No other interferences are anticipated. Retention times expected with different columns and eluents for nitrate are given below.

4.6.8.2 Column and Eluent Selection--

- Column : 500 mm Anion Separator
  Eluent : 0.003 M $NaHCO_3$ + 0.0024 M Na_2CO_3
  Flow : 30%
  Retention time : ∿8 minutes

- Column : 250 mm Anion Seprator
  Eluent : 0.003 M $NaHCO_3$, 0.0024 M Na_2CO_3
  Flow : 35%
  Retention time : ∿4 minutes

4.6.9 Determination of Sulfate ($SO_4^{=}$)

Recommended concentrations for sulfate standards are 0.2, 0.4, 0.6, and 0.8 millimole/liter. A stock solution (20 mM) is first prepared. Dilute solutions are then prepared from the stock solution. Sulfate solutions are stable and may be stored for months. They may be mixed with most other standards except thiosulfate.

- Stock Sulfate Solution (20 mM) from Analytical Concentrate

  Obtain a sulfuric acid analytical concentrate which will make a 0.10 N solution (J. T. Baker Chemical Co., DILUT-IT 1/10 N, #4699). Dilute exactly 1 liter with deionized water following the instructions on the container. This solution is 50 millimolar $SO_4^=$. To make the 20 mM solution pipet exactly 200.00 ml of the 0.05 N solution into a 500 ml volumetric flask and dilute to volume with deionized water. Store in a polyethylene bottle with appropriate label and date.

- Stock Sulfate Solution (20 mM) from Sodium Sulfate

  Weigh out 2.841 grams of dried (105°C) reagent grade anhydrous Na_2SO_4. Transfer to a 1.0 liter volumetric flask and dilute with deionized water. This solution is 20 millimolar $SO_4^=$. Store in a polyethylene bottle with an appropriate label and date.

- 0.8 mM $SO_4^=$

  Pipet exactly 10.00 ml of the 20 mM stock solution into a 250 ml volumetric flask and dilute to volume with deionized water. Mix well and store in a polyethylene bottle with appropriate label and date.

- 0.6 mM $SO_4^=$

  Pipet exactly 15.00 ml of the 20 mM stock solution into a 500 ml volumetric flask and dilute to volume with deionized water. Mix well and store in a polyethylene bottle with appropriate label and date.

- 0.4 mM $SO_4^=$

  Pipet exactly 5.00 ml of the 20 mM stock solution into a 250 ml volumetric flask and dilute to volume with deionized water. Mix well and store in a polyethylene bottle with appropriate label and date.

- 0.2 mM $SO_4^=$

  Pipet exactly 5.00 ml of the 20 mM stock solution into a 500 ml volumetric flask and dilute to volume with deionized water. Mix well and store in a polyethylene bottle with appropriate label and date.

4.6.9.1 Interferences--

When using strong eluents and/or short columns, nitrate ion often coelutes with sulfate. This can be avoided by using standard eluent and a 250 mm or 500 mm column. However, in those solutions, the nitrate concentration should be much lower than sulfate. No other interferences are anticipated. Retention times expected with different columns and eluents for sulfate are given below.

4.6.9.2 Column and Eluent Selection--

- Column : 500 mm Anion Separator

  Eluent : 0.003 M $NaHCO_3$, 0.0024 M Na_2CO_3

  Flow : 30%

  Retention time: 12 minutes (after NO_3^-)

- Column : 250 mm Anion Separator

  Eluent : 0.003 M $NaHCO_3$, 0.0024 M Na_2CO_3

  Flow : 35%

  Retention time: 6 minutes (after NO_3^-)

4.7 NON-DISPERSIVE INFRARED - CARBONATE ANALYSIS

The non-dispersive IR spectrometer allows samples to be analyzed without introducing atmospheric carbon dioxide and removes interferring water vapor from the sample prior to CO_2 detection. Briefly, a known volume of sample is injected into an acid pool reactor, pH<2.5. CO_2 is liberated from its buffer solution and carried by a nitrogen gas purge stream through a drying medium to remove water vapor. The dry CO_2 then passes into an IR cell. The amount of CO_2 present is monitored by a recorder equipped with a disc integrator to measure the peak area. Standards of known CO_2 concentration that bracket the sample values are also analyzed. The CO_2 concentration (mmoles/l) is calculated by performing a modified linear least squares regression analysis based on peak areas, standards concentrations, and sample volume data.

SECTION 5

QUALITY CONTROL

Proper sampling procedures and attention to quality control help provide well-documented and representative samples to be analyzed. Reliable analytical results, however, are only obtained from those samples by continuing to apply a sound program of quality control.

5.1 DATA LOGGING

Separate notebooks will be used to contain the results from different types of analyses. During the analyses, all intermediate data will be recorded. All final results will be recorded by the lead chemist in a central summary notebook which contain data sheets as shown in Figures 3-6 through 3-8. During the transfer of data, the lead chemist will spot check all analytical calculations. Quality control sample values will be closely examined for any unacceptble variance which may have occurred.

5.2 QUALITY CONTROL SAMPLES

Quality control (QC) samples will be included with each batch of field samples that is analyzed. QC samples are especially important in off-site analyses performed as part of a contract program. Equipment in an off-site location may be functioning in a less than optimum environment. The use of QC samples can help to detect such problems.

A quality control sample has the following characteristics: (1) it contains species in the same concentration range as those samples being analyzed; (2) the concentrations of the species in the QC sample are accurately known; and (3) the concentrations of the species of interest do not vary over time.

A QC sample may be produced several ways. A synthetic sample containing the species of interest can be made up in the laboratory. The sample is then analyzed at Radian, Austin, to determine the concentrations of the species and any problems with long-term stability. The sample can then be transported to an off-site laboratory and analyzed with batches of samples at the off-site location. The analytical results should be compared to the results generated at Radian, Austin, as well as, on site.

Another method of generating a QC sample is to take a large volume sample from a process stream, analyze the sample initially, and then compare this result to repeated analyses of the sample with other batches of samples over a period of time. This type of QC sample has an advantage over a synthetic sample because it comes from an actual process stream that is being analyzed. If there is any change in species concentrations over time there is a good chance that the same change is occurring to process samples initially analyzed and then stored for the life of the program.

It is useful to plot the quality control sample results each time they are analyzed. This procedure allows the analytical team in the field to quickly spot any trends, or drifts, that might be developing in the analytical procedures. After the QC data has been plotted a few times, acceptable error limits can be established for the analytical results of the quality control samples from the various procedures used in the laboratory. When quality control values fall outside these boundaries, it is a definite indication that other samples analyzed in the same group should be suspected, and the analyses should be repeated.

5.3 AUDIT SAMPLES

Audit samples sent to the field from Austin will also be analyzed. An audit sample is a sample in which the concentrations of certain species have been determined by the best (most accurate) methods. The sample is then analyzed at the field location using the analytical methods employed there. The results of the analyses are compared to determine if any differences exist. This sample is then typically used as a QC sample at the field laboratory.

An alternative approach for an audit sample is to send a sample that is prepared in Austin to the field. The analysis is done in the field and the results sent back to Austin along with the sample. Then the sample is analyzed in Austin and the results compared. This type of technique is known as the "ringer" method.

5.4 REPLICATE ANALYSES

Another useful technique for spotting analytical problems is to run some fraction of the samples in duplicate. While the quality control samples can be used to determine the overall accuracy of the analysis, duplicate samples can be used to determine the precision of the analysis. Another approach that is often used is to run some fraction of samples that have been previously analyzed along with a batch of unknown samples. The analytical results of the most recent analysis are then compared to determine how stable field samples are over periods of time. If the most recent analysis provides a higher or lower number than the original analysis, then it is possible that the samples are unstable when stored.

5.5 STANDARD ADDITIONS AND SPIKED SAMPLES

In addition to periodic running of quality control and audit samples, other techniques can be used to insure that routine analyses are being done correctly. Two such methods that can be applied are the technique of standard additions and the spiking of samples.

The method of standard additions is often used to determine if the values obtained for unknowns correspond to some linear response. This method is especially useful for atomic absorption, ion chromatography, and specification electrode analyses. In the standard addition technique a typical calibration curve is prepared. Measurements are then obtained for an aliquot of an unknown and for an identical aliquot to which a known quantity of the species of interest has been added. The concentration of the species in each solution is then calculated from the calibration curve. The difference in concentrations for the two aliquots should be equal to the known quantity added unless there has been an enhancement or a depression of the normal response. If a discrepancy is found, the apparent concentration of the unknown is multiplied by the ratio of the true quantity added to the apparent amount added. This correction assumes that the calibration curve is essentially linear in the region of measurement and that the relative enhancement or depression of the response is the same for the aliquots.

The disadvantage of this analytical approach is that a number of additional samples are generated that require analysis. When a number of unknowns are to be analyzed, it is often not convenient to attempt analysis of all the samples by this method. A judicious selection of a few samples from different collection points for analysis by this method will provide a good quality control check and should be performed at least once during the life of the analytical program.

Another method of checking analytical results is to take selected samples and "spike" the samples with a known amount of standard. The samples are reanalyzed to see if the analytical results obtained accurately reflect the addition of the spike.

Then the recovery is said to be 100%. Variations in the recovery are reported as a ratio of the total concentration found to the total concentration that should be present.

5.6 ADDITIONAL CONSIDERATIONS

In a field location, it is important to have at least one alternative method of analysis available for each major species of interest. If time permits, a batch of samples can be analyzed by both techniques and the results compared. This approach is often used to determine which method is the best to use in the field, given the time constraints of the program.

Within the laboratory, all balances will be checked weekly with a standard reference weight set. Additional maintenance and calibration may also be required of any instrumentation used in analyses. Therefore, a complete operations and maintenance manual will accompany any instrument taken to the field location.

APPENDIX I

PLANT 9677

Plant 9677 is a 3160 MW electric power generating station, consisting of four units. Units 1 and 2 are 700 MW each and Units 3 and 4 are 880 MW each. All units burn bituminous coal from Eastern Kentucky in Bureau of Mines Districts 8 and 9. An analysis of a coal samples taken during a visit to the plant on 10/29 - 10/31/79 is presented in Table I-1. The boilers are tangential-fired and result in about 67 percent of the total ash being fly ash and 33 percent as bottom ash.

Plant 9677 uses wet sluicing and ponding for disposal of both fly ash and bottom ash from all four units. A small portion of fly ash is collected dry and sold locally. Both bottom and fly ash are disposed of in a common pond. Other streams which also enter the ash pond include roof and floor drains (about 5700 liters/min or 1500 gpm). A conceptual diagram of the pond system is shown in Figure I-1.

Plant 9677 has the option of using cooling tower blowdown or ash pond water to sluice bottom and fly ash, as shown in Figure I-1. Plant makeup water is taken from a nearby river and used for cooling tower makeup. The cooling towers generally operate at 2-3 cycles of concentration. The portion of cooling tower blowdown not used to sluice ash is mixed with the ash pond overflow (after pH adjustment) before being discharged.

The total ash production at Plant 9677 under full load conditions is about 72,000 kg/hr (80 tons/hr) fly ash and 35,500 kg/hr (39 tons/hr) bottom ash for all four units (based on 10 percent ash in the coal). The average daily sluice rate for fly ash is 50,000 liters/min (13,200 gpm), which

TABLE I-1. COAL AND ASH ANALYSIS FOR PLANT 9677

Coal Ultimate Analysis Species	 Wt %	Ash Mineral Analysis Species	
Moisture	10.25	SiO_2	51.67
Carbon	64.63	Al_2O_3	23.67
Hydrogen	4.45	TiO_2	1.17
Nitrogen	1.49	Fe_2O_3	13.55
Chlorine	0.05	MgO	1.26
Sulfur	1.89	CaO	2.35
Ash	11.07	K_2O	2.80
Oxygen (diff)	6.17	Na_2O	0.54
	100.00	SrO	0.00
Heating Value = 11,630 Btu/lb		BaO	0.09
		SO_3	0.87

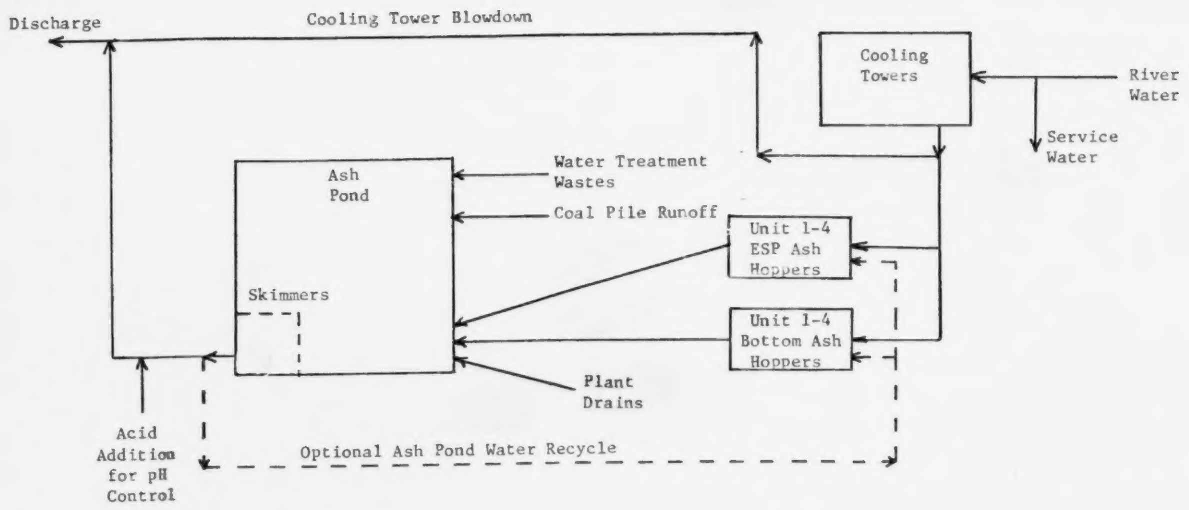
Discharge
Cooling Tower Blowdown
Cooling Towers
River Water
Service Water
Ash Pond
Water Treatment Wastes
Coal Pile Runoff
Unit 1-4 ESP Ash Hoppers
Skimmers
Unit 1-4 Bottom Ash Hoppers
Plant Drains
Acid Addition for pH Control
Optional Ash Pond Water Recycle

Figure I-1. Plant 9677 Ash Disposal Block Diagram

corresponds to about 4 percent solids in the fly ash slurry. Fly ash is typically sluiced for about 2-1/2 hours every 4 hours. The average daily sluice rate for bottom ash is 44,000 liters/min (11,600 gpm) which corresponds to about 2.7 percent solids in the bottom ash slurry. The instantaneous level of solids in the ash slurries can vary significantly. During a sluicing operation, the solids content of the slurry generally starts at a high value and decreases as ash is removed from a particular hopper or set of hoppers.

At Plant 9677, the bottom ash is conveyed from the boilers to the ash pond through 25 cm (10 inch) diameter pipes. One pipe is used for each boiler. The distance from the boilers to the ash pond entry point varies from 490 meters (1600 feet) for Unit 1 to 690 meters (2,260 feet) for Unit 4. The fly ash from Units 1 and 2 is collected by electrostatic precipitators and slurried to the ash pond in 25 cm (10 inch) diameter pipes (one per boiler). The fly ash from Units 3 and 4 is also collected by electrosttic precipitators and sluiced in 25 cm (10 inch) diameter pipes to the ash pond. Two pipes for each of Units 3 and 4 are used to sluice fly ash.

The plant floor and roof drains are collected and enter the ash pond at the same point as the fly ash and bottom ash. The ash pond has a surface area of about 1.1 million square meters (270 acres) with an average depth of 14 meters (46 feet). As shown in Figure I-1, the pond overflow pH is adjusted with sulfuric acid prior to mixing with cooling tower blowdown and final discharge.

APPENDIX G

PILOT SCALE INVESTIGATION OF CLOSED-LOOP ASH SLUICING FIELD TEST PLAN FOR PLANT 9991

DCN 82-211-004-31

PILOT SCALE INVESTIGATION OF CLOSED-LOOP ASH SLUICING

FIELD TEST PLAN FOR PLANT 9991

15 November 1982

by

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EPA Contract Number 68-02-3163

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SECTION 1

INTRODUCTION

1.1 BACKGROUND

The use of coal in steam-electric utility plants may increase in the coming years as supplies of natural gas and oil decline and become more expensive. However, unlike natural gas and oil, the combustion of coal produces significant amounts of solid waste in the form of fly ash and bottom ash. Frequently, utility plants transport ash by mixing with water and sluicing the mixture to a large nearby pond. The ash usually settles rapidly and clarified overflow water is discharged to a stream or river.

The intimate mixing of fly ash and water causes soluble species (such as Ca, Cl, SO_4, and trace metals) to be leached from the ash. An increase or decrease in the pH level can also result, depending on the characteristics of the coal ash. The discharge of pond water containing high levels of these dissolved species and suspended ash is environmentally unacceptable. One means of eliminating discharge from the pond is to recycle all overflow water for reuse as makeup to the ash sluice system. As the concentrations of dissolved species increase in a closed-loop recycle system, the potential for scale formation in process lines and equipment also increases. Typically, the major scaling species are calcium carbonate ($CaCO_3$) and gypsum ($CaSO_4 \cdot 2H_2O$). The potential for scale formation from these species can be controlled by various water treatment methods, such as pH adjustment and softening.

Design and operation of closed-loop recirculating ash sluice water systems require a reliable method for predicting and preventing potential scale formation. To achieve this goal, the U.S. Environmental Protection Agency is sponsoring a two phase research and development program. Phase I focused on the development of a computer model designed to simulate a recirculating ash sluice water system and various water treatment options. Phase II involves the design, fabrication, and operation of a pilot-scale recirculating ash sluice water system at an existing power plant. The computer model will be used to determine preliminary operating conditions for the pilot unit field tests. Results from the pilot unit field tests will be used to verify and/or modify the computer model and to evaluate the feasibility for recirculating fly ash sluice water.

The purpose of this document is to present the field test plan for operating the ash sluice pilot unit to obtain appropriate process and analytical data at Plant 9991. This section outlines the field test objectives and potential field test limitations. Section 2 briefly describes the pilot unit. Sections 3 and 4 present the proposed field test approach and the overall project organization. Section 5 discusses quality assurance. As additional background, Appendix I presents a brief description of the existing ash sluice system at Plant 9991.

1.2 FIELD TEST OBJECTIVES

The pilot unit field test program for Plant 9991 is designed to achieve three objectives:

1. To demonstrate the technical feasibility of reducing ash system blowdown and for potentially operating a closed-loop recirculating fly ash sluice water system at conditions very similar to those which might be encountered in a full-scale system based on the analyses of samples from Plant 9991;

2. To obtain representative steady-state process and analytical data for input to and verification of the ash sluice computer model; and

3. To quantify as nearly as possible the relative benefits of using various treatment approaches, such as pH adjustment and side-stream softening, for control of potential scale formation in the process equipment when minimizing system blowdown.

The pilot unit will be operated at two ash sluice rates (5 wt. % and 10 wt. %) with three levels of recycle water treatment: no treatment, pH adjustment, and sidestream softening. The primary goal of each test will be operation at minimum system blowdown flow rate (maximum recycle flow rate). Initially, the ash sluice computer model will be used to estimate the minimum blowdown flow rates for each test. Results from operating the pilot unit at these blowdown flow rates will then be used to verify computer model predictions and to provide a basis for comparison of recycle water treatment alternatives.

1.3 FIELD TEST LIMITATIONS

The pilot unit has been designed to simulate on a reduced scale the basic physical aspects of a full-scale ash sluice water system. For example, the intimate contact of ash and water normally achieved in a sluice line is simulated in the pilot unit by rapid agitation of the ash and water in the slurry mix tank. Similarly, the settling of ash particles in a pond is simulated by removal in two parallel filter presses. Even though these basic physical aspects can be simulated, the ultimate effect on sluice water chemistry and subsequent pilot unit data may be different.

Table 1-1 presents a list of potential field test limitations and the associated impact or resolution of these limitations. Based on available data for the fly ash and sluice water system at Plant 9991, these potential limitations are not anticipated to present significant problems in operating the pilot unit or interpreting pilot unit data. The field test limitations are discussed in more detail as appropriate in Section 3 - Field Test Approach.

TABLE 1-1. FIELD TEST LIMITATIONS

Potential Limitation	Impact/Resolution
Ash residence time and liquid-ash contact time is greater for filter press than for an ash pond.	Not considered to be significant since laboratory tests with sample ash from Plant 9991 indicates rapid leaching rate.
Precipitation in the filter press cannot be accurately predicted prior to field testing.	Material balances around ash mixing tank and filter press will identify degree of precipitation; these data can be used to revise operating conditions for achieving minimum blowdown.
Carbon dioxide transfer from the atmosphere to the recycle water.	Analyses of recycle water samples from Plant 9991 indicate no significant CO_2 transfer; additional sampling is planned for Plant 9991 ash pond during pilot unit field testing to confirm preliminary results.
Increased system volume and testing time required for sidestream softening tests.	Sidestream softening tests will be performed at the conclusion of each test series to ensure completion of other tests; it may be necessary to eliminate sidestream softening of recycle water for a 10 wt. % slurry if constrained by schedule.
Identification of solids precipitation (scaling) in recycle line.	In addition to visual inspection of heated test spools in the recycle line, on-site laboratory studies will be conducted to determine the solubility level of potential scaling species in the recycle line.
Comparability of aqueous phase chemistries for pilot unit and Host Station.	Due to the complexity of the Host Station system, direct comparison of analytical results may not be possible; however, potential scaling species (calcium carbonate and gypsum) should be identical and basic treatment approaches should be applicable.

SECTION 2

ASH SLUICE PILOT UNIT

The ash sluice pilot unit consists of six portable skid-mounted equipment modules and one control/laboratory building. Each skid is approximately 2.4 by 3 meters (8 by 10 feet). The entire test system fits into an area no larger than 6.1 by 12.2 meters (20 by 40 feet). The pilot unit consists of four basic segments:

- a makeup/recycle tank, a fly ash storage bin and feeder, and a fly ash mixing tank to duplicate the sluicing process;
- a treatment reaction tank to allow additional mixing time prior to sluicing;
- a filter press to simulate the ash pond; and
- an acid feed system and a softener/clarifier to treat recycle water for the prevention/control of scale formation.

These skid-mounted equipment modules are interconnected by flexible water hoses and electrical couplings. An overall flow scheme of the pilot unit is presented in Figure 2-1.

In addition to the basic equipment modules, a test loop assembly is included to monitor the scaling and corrosion effects in the sluice water recycle line. The test loop assembly will consist of two 5.1-cm (nominal 2-inch) diameter schedule 40 stainless steel pipe spools mounted in a parallel configuration. The spools will be identical 0.9 meter (3.0 foot) lengths, flanged for easy removal. The spools will be heat traced and insulated in order to maintain a wall temperature of 49°C (120°F). The parallel configuration is valved such that a spool can be easily removed for visual inspection.

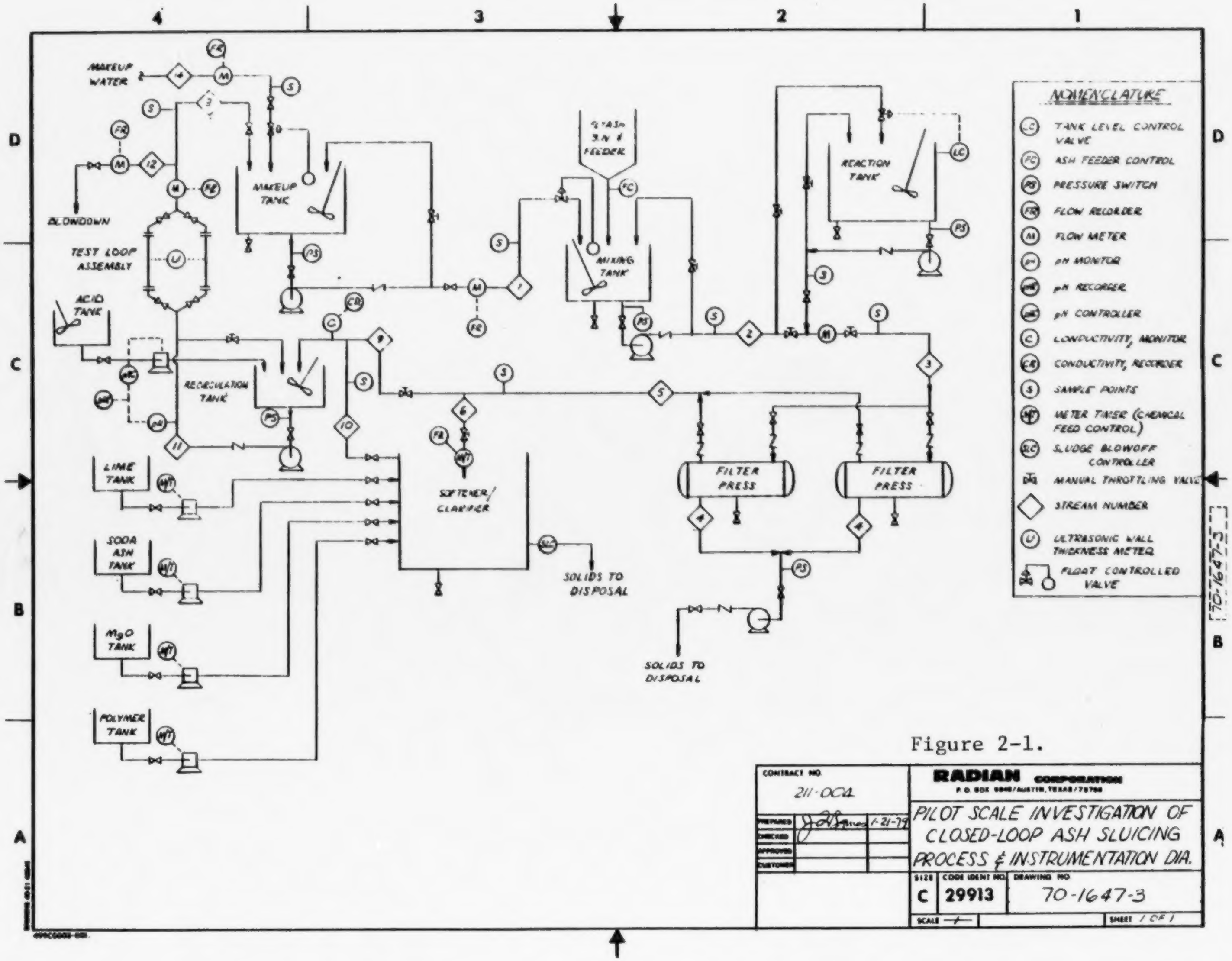
MAKEUP WATER
BLOWDOWN
TEST LOOP ASSEMBLY
ACID TANK
MAKEUP TANK
RECIRCULATION TANK
LIME TANK
SODA ASH TANK
MgO TANK
POLYMER TANK
ASH BIN & FEEDER
MIXING TANK
SOFTENER/ CLARIFIER
SOLIDS TO DISPOSAL
REACTION TANK
FILTER PRESS
FILTER PRESS
SOLIDS TO DISPOSAL
NOMENCLATURE
LC TANK LEVEL CONTROL VALVE
FC ASH FEEDER CONTROL
PS PRESSURE SWITCH
FR FLOW RECORDER
M FLOW METER
pH pH MONITOR
pHR pH RECORDER
pHC pH CONTROLLER
C CONDUCTIVITY, MONITOR
CR CONDUCTIVITY, RECORDER
S SAMPLE POINTS
MT METER TIMER (CHEMICAL FEED CONTROL)
SLC SLUDGE BLOWOFF CONTROLLER
MANUAL THROTTLING VALVE
STREAM NUMBER
U ULTRASONIC WALL THICKNESS METER
FLOAT CONTROLLED VALVE
70-1647-3
CONTRACT NO 211-OCA
PREPARED 1-21-79
CHECKED
APPROVED
CUSTOMER
RADIAN CORPORATION
P.O. BOX 9948/AUSTIN, TEXAS/78766
PILOT SCALE INVESTIGATION OF CLOSED-LOOP ASH SLUICING PROCESS & INSTRUMENTATION DIA.
SIZE C
CODE IDENT NO. 29913
DRAWING NO 70-1647-3
SCALE —
SHEET 1 OF 1

Figure 2-1.

SECTION 3

FIELD TEST APPROACH

Pilot unit field testing at Plant 9991 will focus on determining the technical feasibility of operating a closed-loop recirculating fly ash sluice water system and obtaining steady-state process and analytical data for verification of the ash sluice computer model. Three levels of recycle water treatment will be investigated:

- no treatment,
- pH adjustment, and
- sidestream softening a portion or all of the recycle water combined with pH adjustment.

For each level of treatment, a constant sluice water flow rate of 50 gpm will be maintained to the mix tank. Fly ash will be added to form a slurry containing either 5.0 or 10.0 weight percent solids.

In an effort to determine the technical feasibility of operating a closed-loop fly ash sluice system, the limiting operating conditions must be identified. This will be accomplished by determining the minimum blowdown achievable without scaling in the recycle line for each of the three levels of treatment.

Since actual scale formation in the pilot unit may be limited by factors other than system chemistry, such as time constraints on the individual tests, the specific materials of construction of the pilot unit or system dynamics, a conservative approach will be taken in identifying the minimum blowdown. For each test the minimum blowdown will be designated by the point at which the limiting species ($CaCO_3$ or $CaSO_4 \cdot 2H_2O$) becomes supersaturated (relative saturation > 1.0) in the recycle stream. This approach is based on the assumption that scale would eventually form in the system if the limiting species remained supersaturated in the recycle line.

The computer model quantifies the degree of saturation of a species by calculating a relative saturation value. For example, the relative saturation of gypsum is calculated by the following equation:

$$RS(CaSO_4 \cdot 2_{H_2O}) = \frac{(a_{Ca^{++}})\ (a_{SO_4^{=}})\ (\gamma_{H_2O})^2}{Ksp\ (CaSO_4 \cdot 2H_2O)} \qquad (3\text{-}1)$$

where

$RS(CaSO_4 \cdot 2_{H_2O})$ is the relative saturation of gypsum,

a_i is the activity of free Ca++ or $SO_4^{=}$ ions,

γ_{H_2O} is the activity coefficient of water, and

Ksp $(CaSO_4 \cdot 2H_2O)$ is the solubility product of gypsum.

A calculated relative saturation value less than 1.0 indicates that the solution is subsaturated with respect to that species and therefore no precipitation (or scaling) should occur. A relative saturation value greater than 1.0 indicates a potential for precipitation of the species.

Whether or not a sample is actually supersaturated can be determined by allowing the sample to equilibrate with seed crystals of the species in question. The equilibrated crystals are filtered from solution, dried and weighed. If the weight of the crystals increases, the sample was supersaturated with respect to that species. If the weight decreases, the sample was subsaturated. This procedure will be used in the field to determine the point at which the limiting species becomes supersaturated in the recycle line.

The basic approach for each test will be to use the ash sluice water computer model to estimate initial pilot unit operating conditions. Ash leaching data for the computer model will be provided from laboratory results of batch leaching studies already performed with fly ash from Plant 9991 and deionized water. These studies indicate that the ash is alkaline. Table 3-1 lists the quantities of the various species that leached from the ash during batch leaching (5.0 weight percent) in the laboratory.

TABLE 3-1. RESULTS OF LABORATORY LEACHING STUDIES (5 wt. %)

Species	Quantity Leached (mg/g ash)
Calcium	10.4
Magnesium	-
Sodium	0.36
Potassium	0.02
Chloride	0.02
Sulfate	4.00
Silica	0.07

The pH of the liquid after leaching was 12.0. As the field testing proceeds, these data will be supplemented with actual field leaching data. If the leaching data generated in the field are significantly different from the results of the laboratory study, additional computer simulation cases will be completed to estimate initial operating conditions for the remaining tests.

For each test, the pilot unit will be operated at the estimated conditions until steady state is achieved. At that time, a sample of the recycle stream will be equilibrated with seed crystals of the limiting species ($CaCO_3$ or $CaSO_4 \cdot 2H_2O$). If this procedure indicates that the limiting species is subsaturated, the computer model will be used to estimate new operating conditions (reduced blowdown and increased recycle) and the test will continue at the new operating conditions until supersaturation is attained.

At the conclusion of each steady-state operating period, the test loop assembly and recycle tank will be inspected. Any solids that were deposited during the test will be collected for analysis.

Data generated during operation of the pilot unit at steady state will be compared with the values predicted by the ash sluice water computer model. Any discrepancies will be identified and resolved. A report will be prepared presenting the results of testing at Plant 9991.

3.1 SAMPLING STRATEGY

During the course of field testing, two types of samples will be required. First, samples must be taken periodically to monitor the pilot unit for process upsets and to determine when steady-state operation is achieved. Second, during steady-state operation, samples must be taken to characterize the system. In order to reduce the impact of process water loss due to sampling for operation at low blowdown flow rates, these samples will be kept to a minimum and will be taken at blowdown streams whenever possible.

A list of the samples and other operating parameters used to monitor the pilot unit for steady-state operation are presented in Table 3-2.

The frequency of these samples will depend upon both the system volume for the particular test and the blowdown flow rate. During testing without treatment, a large blowdown flow rate (>40 gpm) will probably be required. For a pilot unit volume of approximately 800 gallons the system

TABLE 3-2. PARAMETERS TO MONITOR FOR STEADY-STATE OPERATION

Sample Point and Parameter		Field Test		
		Minimum Blowdown Without Treatment	Minimum Blowdown With Acid Addition	Minimum Blowdown With Softening
S-1	System Blowdown			
	Ca	✓	✓	✓
	Na	✓	✓	✓
	pH	✓	✓	✓
	Flow Rate	✓	✓	✓
S-2	System Makeup			
	Flow Rate	✓	✓	✓
S-3	Mix Tank Inlet			
	Flow Rate	✓	✓	✓
S-4	Mix Tank Outlet			
	Ca	✓	✓	✓
	Na	✓	✓	✓
	pH	✓	✓	✓
S-8	Filter Press Outlet			
	Ca		✓	✓
	Na		✓	✓
	Alkalinity		✓	✓
	pH		✓	✓
	Recirc Tank Outlet			
	Flow Rate	✓	✓	✓
S-10	Softener Outlet			
	Ca			✓
	Na			✓
	Alkalinity			✓
	pH			✓
	Flow			✓
S-11	Acid Tank[1]			
	Cl[1] or SO_4[1]		✓	✓
	Flow		✓	✓
S-12	Lime Tank			
	Ca[1]			✓
	Wt.% Solids[1]			✓
	pH[1]			✓
	Flow			✓
S-13	Soda Ash Tank			
	Na[1]			✓
	Alkalinity[1]			✓
	pH[1]			✓
	Flow			✓

[1] Per batch basis

will turn over three times in one hour. Therefore, sampling will take place approximately every hour. For lower blowdown flow rates, the frequency of sampling will be reduced to approximately the period required for the system to turn over three times (estimated at four hours for a blowdown of 10 gpm). Because of the increased system volume during sidestream softening and the anticipated reduction in the blowdown flow rate, sampling during sidestream softening tests will be required only two times a day.

When the parameters listed in Table 3-2 show no significant variation (±5%) over two sample periods, the pilot unit will be considered to be operating at steady state. At this time, a complete set of system characterization samples will be taken. These samples are listed in Table 3-3. Each sample will be 500 ml in volume; 100 ml for analysis of major cations (Ca, Mg, Na, K), 100 ml for analysis of major anions (Cl, SO_4, SiO_2), 50 ml for carbonate analysis, and 250 ml which will be appropriately preserved in case additional analyses are required. In addition, a 200 ml sample of the recirculating water will be taken for equilibration with either $CaCO_3$ or $CaSO_4 \cdot 2H_2O$ seed crystals to determine the relative saturation of the species in the recycle water.

Additional details on sample analysis are provided in Section 4, Analytical Methods.

3.2 FIELD TEST FOR MINIMUM BLOWDOWN WITH NO TREATMENT

The purpose of this test is to determine the minimum blowdown flow rate achievable with no treatment of the recycle water. Using ash leaching data obtained from batch leaching of a 5.0 weight percent slurry of fly ash from Plant 9991 and deionized water, preliminary results of computer simulation indicate $CaCO_3$ will be the limiting species for operation without treatment. Based on the assumption that no solids precipitate on the fly ash (with no reduction in the potential for $CaCO_3$ precipitation in the recycle line), the calculated relative saturation of $CaCO_3$ was over 300 for a once-through system. However, based on laboratory studies of batch leaching at higher weight

TABLE 3-3. SAMPLES FOR PILOT UNIT SYSTEM CHARACTERIZATION

Sample Point ID	Sample Point Location	No Treatment	Acid Addition	Softening
S-1	System Blowdown	✓	✓	✓
S-2	Makeup Water	✓	✓	✓
S-3	Mixing Tank Inlet Water	✓	✓	✓
S-4	Mixing Tank Effluent	✓	✓	✓
S-7	Filter Press Solids	✓	✓	✓
S-8	Filter Press Effluent	✓	✓	✓
S-9	Softener/Clarifier Solids			✓
S-10	Softener/Clarifier Effluent			✓
S-11	Recirculation Tank Inlet			✓

percent solids and analytical data for samples of ash sluice system streams at Plant 9991, it appears that a portion of the supersaturated $CaCO_3$ will precipitate on the ash during field testing with the pilot unit. Since the extent of precipitation is not known, a series of computer simulations were completed assuming varying quantities of supersaturated $CaCO_3$ precipitation in either the mix tank or the filter press. The results of these simulations are illustrated in Figure 3-1. As shown, the potential for $CaCO_3$ solids formation (relative saturation) decreases linearly with the percent of supersaturated species precipitated. The estimated gypsum relative saturation in the recycle line, assuming no precipitation of $CaCO_3$ in the mix tank and/or filter press, is 0.3.

As reflected by the high calcium carbonate relative saturation levels, the potential for $CaCO_3$ precipitation in the recycle line is significant even if a large percentage (>80%) of the supersaturated species is assumed to precipitate in the mix tank and/or filter press. For this reason, the pilot unit initially will be operated as a once-through system. After steady-state operation has been achieved, a sample of the blowdown will be equilibrated with $CaCO_3$ seed crystals to determine if the relative saturation of $CaCO_3$ in the blowdown is greater than 1.0 as anticipated. If not, a new estimate of the minimum blowdown will be made based on the data generated during operation of the pilot unit. Testing will continue with partial recycle until the relative saturation of $CaCO_3$ in the recycle water exceeds 1.0.

During testing, the parameters used for monitoring system operation and steady-state determination will be plotted on-site. The primary purpose of this activity will be to identify any unusual data points, such as potential analytical error or process upsets, so that they may be verified prior to completion of the test. When steady state has been achieved, the analytical results of the system characterization samples, along with the appropriate process data, will be used to calculate material balances around the mix tank, the filter press and the overall system. Again, this activity will be

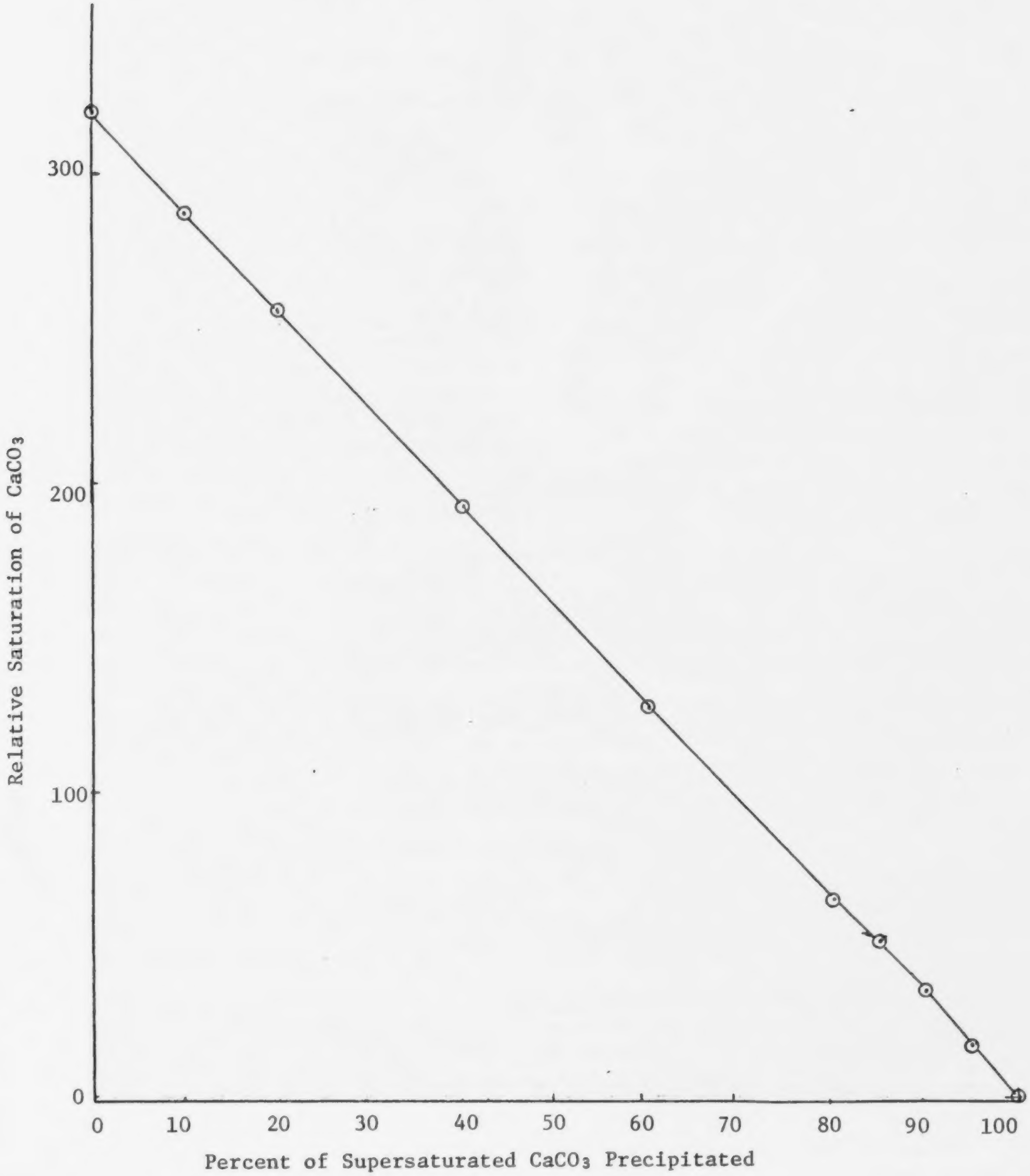

FIGURE 3-1. $CaCO_3$ relative saturation as a function of percent of supersaturated $CaCO_3$ precipitated (once-through system, 5 weight percent solids).

completed on-site so that any inconsistencies or problems can be identified and resolved. The equations used for each of these calculations are presented below:

mix tank: $$([X]_{mto} - [X]_{mti})(Q_{mu} + Q_{rc}) = (\chi_{ash})(Q_{ash})(10^6) \qquad (3\text{-}2)$$

filter press: $$([X]_{mto})(Q_{mu} + Q_{rc}) = ([X]_{bd})(Q_{rc} + Q_{bd} + Q_{fp}) \qquad (3\text{-}3)$$

overall: $$([X]_{mu})(Q_{mu}) + (10^6)(\chi_{ash})(Q_{ash}) = ([X]_{bd})(Q_{bd} + Q_{fp}) \qquad (3\text{-}4)$$

where

$[X]$ is the concentration of species X (ppm) in the mix tank inlet (mti), the mix tank outlet (mto), the makeup (mu), and the blowdown (bd),

χ is the weight fraction of species X leaching from the fly ash,

and

Q is the flow rate (lb/min) of the makeup (mu), recycle (rc), ash (ash), and water occluded with solids in the filter press (fp).

Based on the material balance around the mix tank, the apparent leaching rate will be determined. As the soluble species leach from the ash in the mix tank, the increase in pH and calcium and carbonate ion concentrations will lead to an extremely high driving force for the precipitation of $CaCO_3$. It is anticipated that this high driving force will result in some precipitation of the supersaturated $CaCO_3$ in the mix tank. Since the actual leaching cannot be separated from the precipitation in the mix tank, based on chemical analysis of the inlet and outlet streams, an apparent leaching rate will be used to account for both of these reactions. This data will be used to supplement the leaching rate calculated from laboratory tests with ash samples collected at Plant 9991.

The purpose of the material balance calculation around the filter press is to determine if additional leaching and/or precipitation occurs in the filter press. The pilot unit utilizes two filter presses which are used alternately. Solids are removed from the filter presses in a batch mode. Because of the operation of the filter presses, it will be difficult to determine the quantity of solids in a filter press or to get a representative sample of the solids. For these reasons, the water lost with the solids may be difficult to measure directly. If this is the case, the flow rate will be estimated based on the total makeup to the system and the blowdown flow rate.

The overall material balance will be used to verify the accuracy of the analytical and process data used for this calculation.

3.3 FIELD TEST FOR MINIMUM BLOWDOWN WITH ACID ADDITION

The purpose of this set of tests will be to determine the minimum blowdown flow rate achievable with acid addition. The high $CaCO_3$ relative saturation values anticipated during testing with no treatment indicate a significant potential for $CaCO_3$ precipitation. In other water systems, a common method for reducing the potential for $CaCO_3$ precipitation is pH adjustment by the addition of acid. During pilot unit testing, two acids will be considered: hydrochloric acid (HCl) and sulfuric acid (H_2SO_4). By reducing the potential for $CaCO_3$ precipitation, the blowdown flow rate can be reduced (recycle increased). However, as the system is concentrated, the potential for precipitation of other species (such as gypsum) increases. Therefore, the minimum blowdown during testing with acid addition may be limited by a maximum gypsum relative saturation of 1.0.

The approach used during testing with acid addition will be similar to testing with no treatment. Based on laboratory and field leaching data, initial pilot unit operating conditions will be estimated by computer simulation. After steady-state operation is achieved, samples will be taken to completely characterize the system and the relative saturation of gypsum will be determined by a laboratory procedure. If the system is not supersaturated with respect to gypsum, a new estimate of operating conditions for minimum blowdown will be made and testing will continue. This process will be repeated twice: once for pH adjustment with hydrochloric acid and once for pH adjustment with sulfuric acid.

Using ash leaching data from laboratory studies, a series of preliminary computer simulation cases was completed to determine the gypsum relative saturation for reduced blowdown flow rates when the pH is adjusted to maintain a $CaCO_3$ relative saturation between 0.9 and 1.1. The results of these simulations are illustrated in Figures 3-2 and 3-3.

As shown, the minimum blowdown (gypsum relative saturation = 1.0) for pH adjustment with hydrochloric acid is approximately 7.0 gpm. When sulfuric acid is used, the minimum blowdown will be approximately 30.0 gpm. This higher blowdown flow rate is due to the greater relative saturation of calcium sulfate when H_2SO_4 is used.

These preliminary simulations were based on laboratory leaching data and the assumption that 80% of the supersaturated $CaCO_3$ precipitated either in the mix tank or in the filter press prior to pH adjustment of the recycle stream. Data generated during testing with no treatment will be used to complete additional computer simulation cases with updated pilot unit information to better estimate the initial target operating conditions.

Figure 3-3 illustrates the pH required at a given blowdown flow rate to maintain the $CaCO_3$ relative saturation between 0.9 and 1.1. For a given blowdown flow rate, a slightly higher pH ($\sim$0.1 units) can be tolerated when sulfuric acid is used. This is probably due to the ion pairing of calcium and sulfate which makes a portion of the calcium unavailable for precipitation as $CaCO_3$.

The on-site data reduction during acid addition testing will be similar to that described for testing without treatment. The parameters listed in Table 3-1 will be plotted to identify unusual trends and material balance

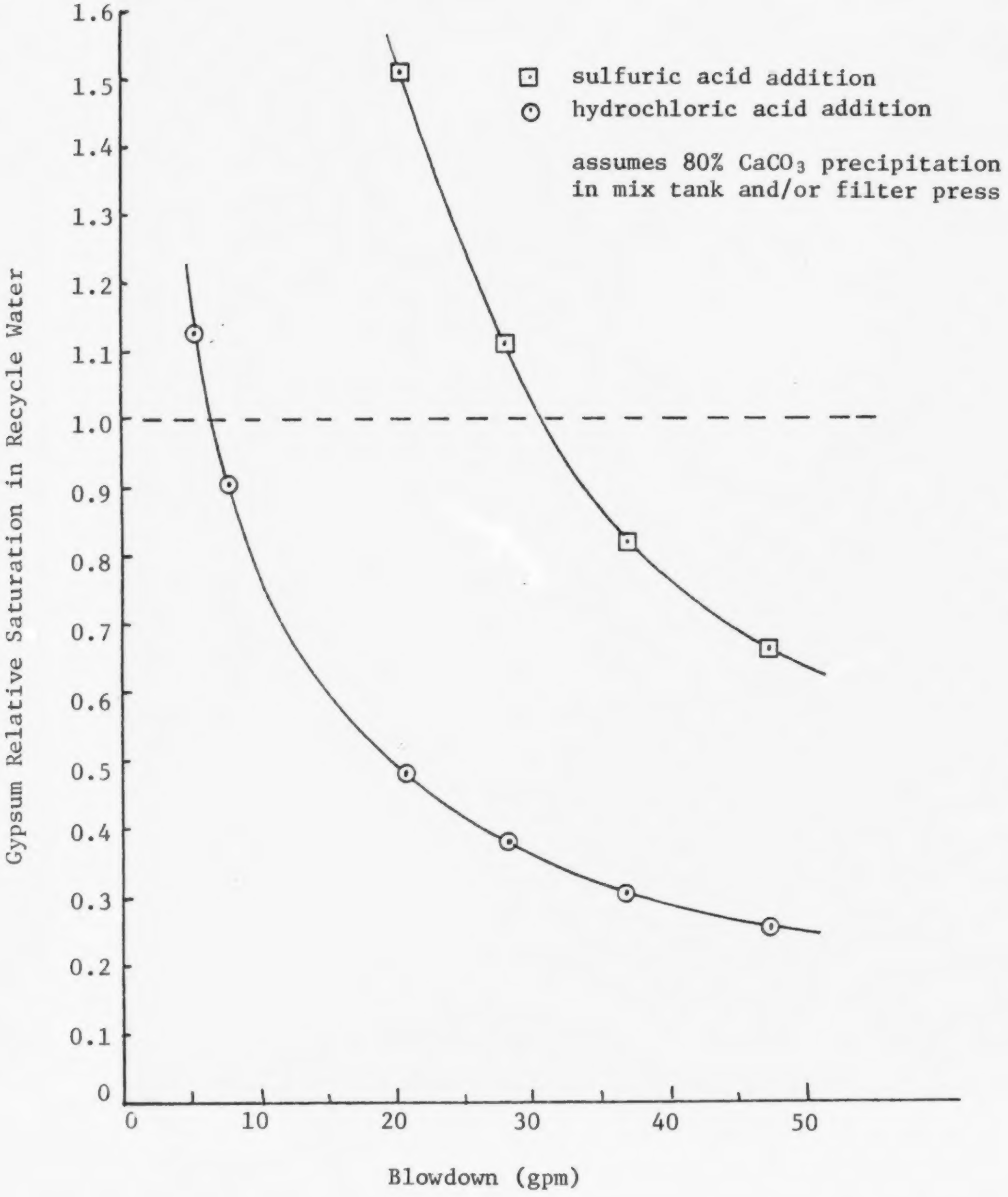

Figure 3-2. Gypsum relative saturation as a function of blowdown flow rate at constant $CaCO_3$ relative saturation (0.9 to 1.1)

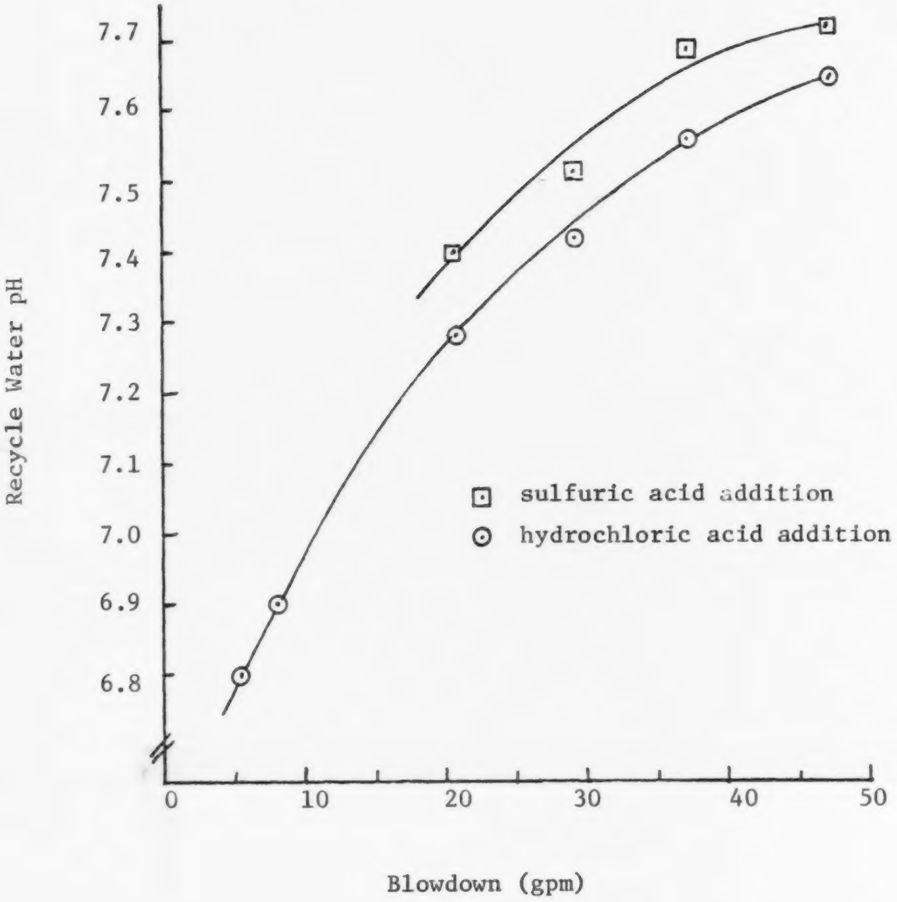

Figure 3-3. Recycle water pH as a function of blowdown flow rate at constant $CaCO_3$ relative saturation (0.9 to 1.1)

calculations will be performed using the analytical results and process data generated during steady-state operation. Species contributed through the acid stream will be considered during the overall material balance calculation.

The results of testing with acid adjustment will be compared to the predicted results based on computer simulation. Any discrepancies will be identified and resolved.

3.4 FIELD TESTING FOR MINIMUM BLOWDOWN WITH ACID ADDITION AND SIDESTREAM SOFTENING

The purpose of these tests is to determine the minimum blowdown flow rate achievable by using a combination of acid addition for pH adjustment and sidestream softening. Based on the preliminary computer simulation results presented in Section 3.3, zero blowdown cannot be achieved with acid addition alone. To further reduce the blowdown, the potential for precipitation of gypsum must be reduced. This requires the removal of liquid phase calcium from the system by softening a portion or all of the recycle stream.

Based on laboratory leaching data and the assumption that 80% of the $CaCO_3$ would precipitate on the fly ash in the mix tank or filter press, a series of simulation cases was completed. The results of these simulations indicate that zero blowdown is achievable during testing with softening and acid addition using sulfuric acid (hydrochloric acid addition will not be used during the softening test due to time constraints). During the 5.0 weight % slurry test, approximately 27 gpm of the recycle water must be softened. The resulting calcium concentration in the recycle stream is estimated to be approximately 450 mg/l. For testing with a 10.0 weight % ash slurry, virtually all of the recycle stream must be softened.

If pilot unit testing with no treatment and acid addition indicates that less than 80% of the supersaturated $CaCO_3$ precipitates in the mix tank, the quantity of recycle that must be treated will increase. Consequently, for the 10.0 weight % ash slurry test, a blowdown may be required.

The pilot unit softener was designed for a flow rate of 46 gpm. If the amount of water being treated is less than 46 gpm, the residence time in the softener increases from the design value of 1.0 hours. This is not expected to be a problem unless the flow rate of the sidestream becomes less than approximately 10 gpm. At this low flow rate, the increased residence time may increase the calcium removal efficiency to a level inconsistent with most commercial systems. This will be considered when evaluating the results of the softening tests.

The procedure described previously for monitoring the pilot unit to determine when steady-state operation is achieved will be used during testing with sidestream softening. One difference will be the addition of the following material balance calculation for the sidestream softener:

$$[X]_{rc}Q_{si} + [X]_{ch}Q_{ch} + 10^6\chi_{chs}Q_{chs} = [X]_{xo}(Q_{so} + Q_{sl}) + \chi_{sls}\,Q_{sls}$$

where

[X] is the concentration of species X in mg/liter for the recycle stream (rc), the softening chemicals (ch), and the softener outlet (so),

Q is the flow rate in lb/min for the softener inlet stream (si), the liquid with the softening chemicals (ch), the solid chemicals (chs), the softener outlet stream (so), the liquid in the softener sludge (sl), and the quantity of solids produced (sls), and

χ is the weight fraction of species X in the solid portion of the softening chemicals (chs) and in the sludge (sls).

The results of testing with sidestream softening and acid addition will be compared to those predicted by the computer model. Any inconsistencies will be identified and resolved.

SECTION 4

PROJECT ORGANIZATION

The project organization for this program is presented in Figure 4-1. Radian's key project personnel are indicated in the figure. The project organization effectively assembles the management and technical interdisciplinary skills needed to successfully execute this project and to coordinate Radian's activities with EPA and Plant 9991 personnel during the program.

Mr. T. R. Blair is Radian's Program Manager. Mr. Blair has extensive experience in large project management and in industrial and pilot unit operations. As Program Manager, Mr. Blair will:

- Administer and supervise all requirements of the contract.
- Be responsible for assuring that required staffing levels and technical expertise are provided to the program.
- Keep Radian management informed on all matters relating to the program.
- Review program reports, directives, work plans, progress reports, and financial reports prior to issue.

Mr. S. L. Winton is Radian's Project Director for the program. Mr. Winton's credentials include vast experience in electric utility water-related projects, knowledge of Radian's chemical equilibrium and process simulation models, and participation in numerous pilot unit and field studies. As

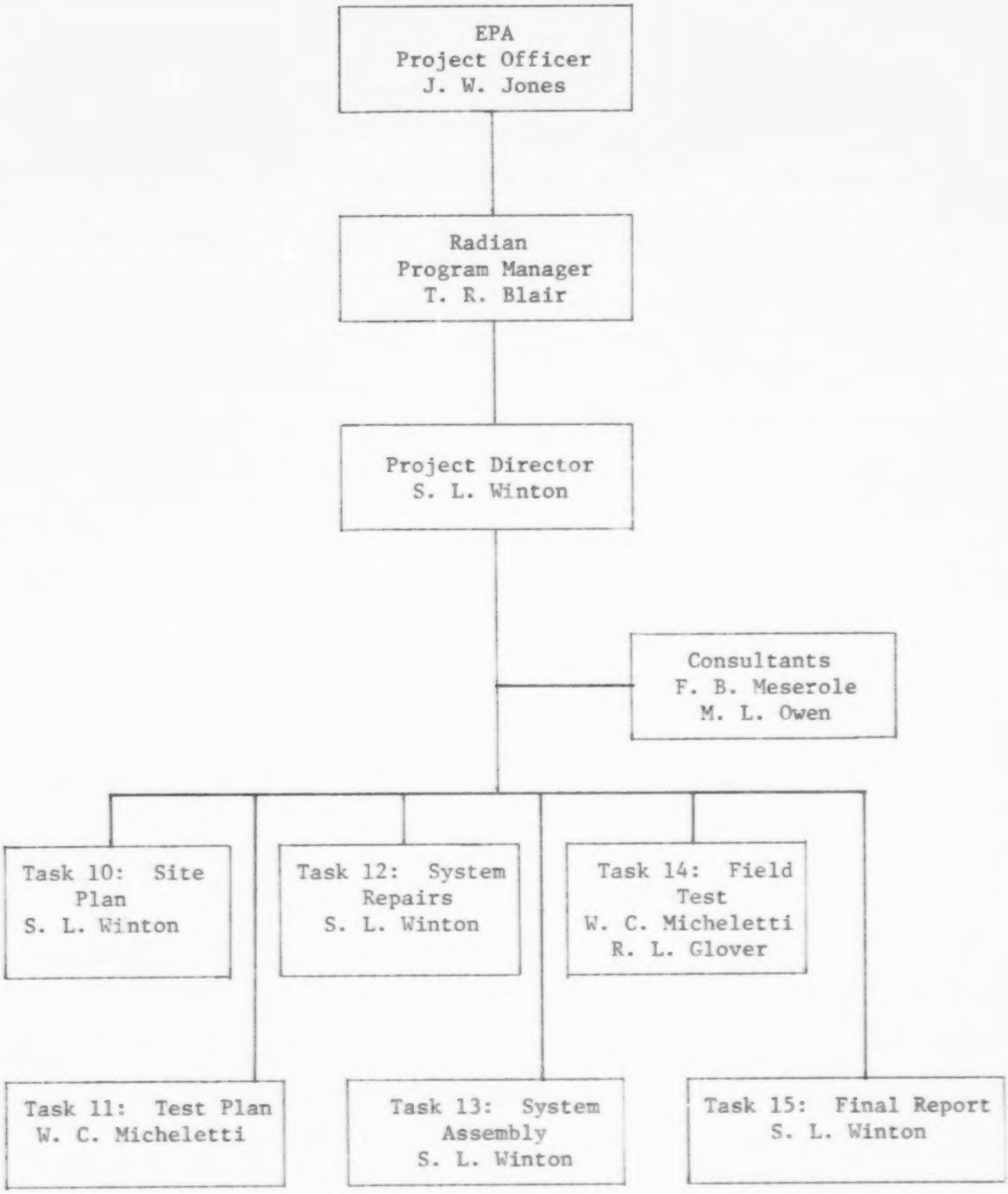
EPA
Project Officer
J. W. Jones
Radian
Program Manager
T. R. Blair
Project Director
S. L. Winton
Consultants
F. B. Meserole
M. L. Owen
Task 10: Site Plan
S. L. Winton
Task 12: System Repairs
S. L. Winton
Task 14: Field Test
W. C. Micheletti
R. L. Glover
Task 11: Test Plan
W. C. Micheletti
Task 13: System Assembly
S. L. Winton
Task 15: Final Report
S. L. Winton

Figure 4-1. Program Organization

Project Director, Mr. Winton is responsible for organizing and directing the overall technical activities and reporting the results of these activities. In performing these duties, Mr. Winton will:

- Establish task objectives and assist in the preparation and review of Work Plans for each task of the program.
- Be responsible for initiating and responding to Work Plan revisions.
- Advise the Program Manager of task achievements, program needs, and potential program problems.
- Assure technical quality of reports, memoranda, and other communications through review of published results.
- Maintain contact with field personnel and coordinate all critical decisions involving technical matters.
- Confer with the Program Manager in the selection of supporting technical staff and technical consultants. He will be responsible for reviewing their performance throughout the program.

The following members of the technical staff are assisting Mr. Winton throughout the program:

- Mr. R. L. Glover
- Dr. F. B. Meserole
- Mr. W. C. Micheletti
- Mr. P. A. Nassos

- Mr. M. L. Owen

- Ms. S. C. Tighe

Each of these individuals provides expertise in one or more of the following areas: inorganic aqueous chemistry, computer simulation, field testing and pilot unit operation, and commercial water treatment systems.

SECTION 5

QUALITY ASSURANCE AND QUALITY CONTROL

The implementation of a comprehensive quality assurance/quality control (QA/QC) strategy is essential to assure the accuracy and validity of data collected in any area of environmental measurements. Radian's technical approach to pilot scale investigation of closed-loop ash sluicing will incorporate a comprehensive QA/QC strategy into all phases of the pilot unit testing program. The major objective of the QA and QC efforts will be to provide data which are of known quality with respect to:

- precision
- accuracy
- completeness,
- representativeness, and
- comparability.

Prior to the initiation of the field testing efforts, an overall quality assurance plan will be designed. This plan will be documented in a Quality Assurance Project Plan (QAPP). The QAPP will be prepared according the the protocol described in the EPA document "Guidelines and Specifications for Preparing Quality Assurance Project Plans," QAMS-005/80.

Successful fulfillment of the objectives of the project will require that sound QA/QC practices be observed throughout all phases of the pilot unit testing. The measurement efforts conducted for this program will include a system of routine internal procedures for assuring that the data output meets the prescribed criteria for data quality. Inherent and implied in this control function is a parallel function of measuring and defining the quality of the data output. The QC and measurement procedures will be designed with statistical considerations which will allow the expected precision, accuracy, detection limits and operating limitations of each of the methods to be defined. The QA/QC effort will focus on the following:

- reasonableness of the measurement data in light of theoretical considerations;
- calibration documentation, frequencies, and traceability;
- potential systematic bias;
- integration of frequent data review into the validation scheme;
- use of computerized data acquisition and data reduction, where applicable, to reduce random error;
- evaluation of extraneous sources of variations;
- compliance of the sampling/analytical process with rigid chain of custody procedures to assure sample integrity; and
- integration of control procedures into the methodology to provide fail-safe warning of out-of-control systems, making extensive use of repeat and replicate samples, control samples and specific acceptance criteria.

The control procedures, which are also used to define the data quality in terms of precision and accuracy, will include the following:

- reagent blanks,
- analytical system blanks,
- calibration standards,
- replicate analyses,
- replicate samples,
- control sample analyses, and
- audit samples.

The chemistry coordinator, Mr. P. A. Nassos, will assume overall responsibility for implementing the project-specific quality control program as outlined in the QAPP. The quality assurance coordinator, Mr. D.L. Lewis, will be responsible for preparation of the QAPP. He will also provide independent review of QC data and activities, as well as independent performance assessment through QA audits. He will thus provide assurance that the overall quality control system is, in fact, performing effectively. This will involve continuing evaluation of the adequacy and effectiveness of the QC system with a view to having corrective measures initiated where necessary.

APPENDIX I

PLANT 9991

Plant 9991 is a nominal 1000 MW electric generating station consisting of two identical 500 MW units. All units burn low sulfur western subbituminous coal from eastern Utah and western Colorado. The coal is washed prior to shipment, resulting in an ash content of approximately 10 weight percent. After combustion, 85 percent of the ash is produced as fly ash with the remaining 15 percent as bottom ash.

Plant 9991 uses wet sluicing and ponding for disposal of both fly ash and bottom ash from both units. A portion of fly ash is collected dry and sold locally. Bottom ash and fly ash are disposed of in separate ponds. Other streams also enter the ash ponds as makeup and include coal pile runoff and treated wastewaters. A conceptual diagram of the pond system is shown in Figure I-1. The decant from the fly ash pond overflows into the bottom ash pond from which it is recycled. The recycled water is used to supply water to both bottom ash hoppers and fly ash hydrovactors. The system is operated in a closed loop mode. The only anticipated losses from the system are through evaporation and water occluded with the settled ash.

The total ash production at Plant 9991 under full load conditions is about 32,700 kg/hr (38 tons/hr) fly ash and 5800 kg/hr (6.4 tons/hr) bottom ash for both units (based on 10 percent ash in the coal). The average daily sluice rate for fly ash is 11,700 liters/min (3080 gpm), which corresponds to about 5 weight % solids in the fly ash slurry. Fly ash is sluiced continuously. The daily sluice rate for bottom ash is 11,400 liters/min (3000 gpm) which corresponds to about 17 weight % solids in the bottom ash slurry.

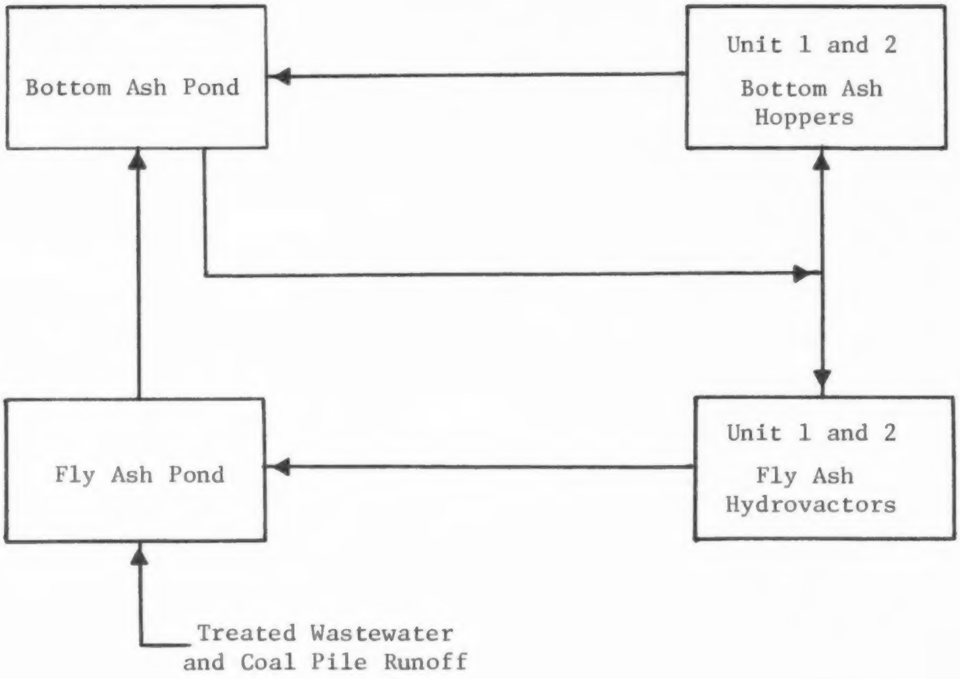
Bottom Ash Pond
Unit 1 and 2
Bottom Ash
Hoppers
Fly Ash Pond
Unit 1 and 2
Fly Ash
Hydrovactors
Treated Wastewater
and Coal Pile Runoff

Figure I-1. Plant 9991 Ash Disposal Block Diagram.

Bottom ash sluicing is carried out once per day for approximately one hour. The instantaneous level of solids in the ash slurries can vary significantly. During a sluicing operation, the solids content of the slurry generally starts at a high value and decreases as ash is removed from a particular hopper or set of hoppers.

At Plant 9991, the bottom ash is conveyed from the boilers to the ash pond through 25 cm (10 inch) diameter pipes. One pipe is used for each boiler. The fly ash is collected by electrostatic precipitators and slurried to the ash pond in 35 cm (14 inch) diameter pipes (one per boiler). During the proposed test, only ash from the upper precipitator of Unit 1 will be available.

The plant coal pile runoff and treated wastewater are collected and enter the fly ash pond at the same point as the fly ash. The makeup water to the system is a blend of these two streams which will vary, depending on plant operations. Treated wastewaters consist of plant runoff and demineralizer regeneration wastes which have been neutralized and clarified prior to entering the ash system.

APPENDIX H

QUALITY ASSURANCE/QUALITY CONTROL PLAN

PILOT SCALE INVESTIGATION OF CLOSED-LOOP ASH SLUICING

QUALITY ASSURANCE PROJECT PLAN

22 September 1982

Prepared by:

D.L. Lewis and P.A. Nassos
Radian Corporation
8501 MoPac Blvd.
Austin, Texas 78759

Approval:

Radian Program Manager ____________ Date: Sept 22, 1982
Radian Project Director ____________ Date: Sept 22, 1982
Radian QA Director ____________ Date: Sept 22, 1982
EPA Project Officer ____________ Date: ____________
EPA QA Director ____________ Date: ____________

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4	SAMPLING PROCEDURES	12	0	09-22-82
5	SAMPLE CUSTODY	7	0	09-22-82
6	ANALYTICAL PROCEDURES	7	0	09-22-82
7	CALIBRATION PROCEDURES	4	0	09-22-82
8	DATA REDUCTION, VALIDATION, AND REPORTING	1	0	09-22-82
9	INTERNAL QUALITY CONTROL CHECKS	12	0	09-22-82
10	PERFORMANCE AND SYSTEMS AUDITS	2	0	09-22-82
11	PREVENTIVE MAINTENANCE	11	0	09-22-82
12	ASSESSMENT OF PRECISION, ACCURACY, AND COMPLETENESS	2	0	09-22-82
13	CORRECTIVE ACTION	3	0	09-22-82
14	QUALITY ASSURANCE REPORTING	1	0	09-22-82

DISTRIBUTION

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SECTION 1

PROJECT DESCRIPTION

Radian Corporation is under contract (EPA Contract 68-02-3163 Mod. 5) to the U.S. Environmental Protection Agency (EPA) to conduct a field test program on a pilot unit ash sluice system at Plant 9991.

This project is part of a two phase research and development program sponsored by the EPA to device reliable methods for predicting and preventing scale formation in closed-loop recycle ash sluice systems. Phase I focused on the development of a computer model designed to simulate a recirculating ash sluice water system and various water treatment options. Phase II involves the design, fabrication, and operation of a pilot-scale recirculating ash sluice water system at an existing power plant. The computer model will be used to determine preliminary operating conditions for the pilot unit field tests. Results from the pilot unit field tests will be used to verify and/or modify the computer model and to evaluate the feasibility of recirculating fly ash sluice water.

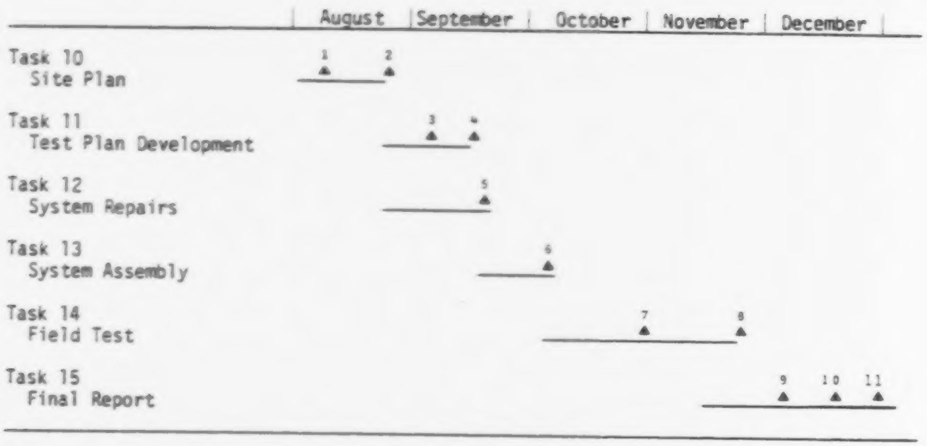
The objectives of the pilot unit field test program for Plant 9991 are:

- To demonstrate the technical feasibility of reducing ash system blowdown and for potentially operating a closed-loop recirculating fly ash sluice water system at conditions very similar to those which might be encountered in a full-scale system based on the analyses of samples from Plant 9991;
- To obtain representative steady-state process and analytical data for input to and evaluation of the ash sluice computer model; and

- To quantify as nearly as possible the relative benefits of using various treatment approaches, such a pH adjustment and sidestream softening, for control of potential scale formation in the process equipment when minimizing system blowdown.

The pilot unit will be operated at two ash sluice rates (5 wt. % and 10 wt. %) with three levels of recycle water treatment: no treatment, pH adjustment, and sidestream softening. The primary goal of each test will be operation at minimum system blowdown flow rate (maximum recycle flow rate). Initially, the ash sluice computer model will be used to estimate the minimum blowdown flow rates for each test. Results from operating the pilot unit at these blowdown flow rates will then be used to verify computer model predictions and to provide a basis for comparison of recycle water treatment alternatives.

The program schedule and milestones are shown in Figure 1-1.



Milestones

1.	8/9/82	Site Visit Complete
2.	8/31/82	Site Selected
3.	9/6/82	Internal Draft of Test Plan
4.	9/12/82	Test Plan to EPA
5.	9/24/82	System Ready for Shipment
6.	10/7/82	System Ready for Operation
7.	11/1/82	5 wt% Tests Complete
8.	11/15/82	10 wt% Tests Complete
9.	12/15/82	Internal Draft of Final Report Complete
10.	12/23/82	Final Report to EPA - Draft
11.		30 Days After Receipt of Review Comments

Figure 1-1. Program Schedule

SECTION 2

PROJECT ORGANIZATION AND RESPONSIBILITY

Project organization for this project is shown in Figure 2-1. The quality assurance (QA) and quality control (QC) functions for this project have been organized to allow independent review of project activities and on-site QC coordination by the person most knowledgable of the sampling/analysis activities.

The QA coordinator for this project is Mr. D.L. Lewis. He will coordinate the development and execution of the QA activities in both the field sampling and chemical analysis phases of the project. He is responsible for preparing the QA Project Plan, coordinating performance and systems audits, and documenting the results of QA/QC activities.

Mr. P.A. Nassos, as Chemistry Coordinator, will assume overall responsibility for implementation of the internal QC program although the lead chemist on-site will coordinate the QC activities for the on-site sampling and analysis. Mr. Nassos will define specific QC procedures for each type of sampling and analysis activity. He will conduct any necessary training sessions, schedule all QC activities, review all instrument calibrations, and coordinate the reporting, record keeping, and QC data analysis for the various activities.

This organization of QA/QC has proven to be effective in past Radian sampling/analysis programs. The QC coordinator, as a key person in the project management team, becomes aware of problem areas and project priorities as they arise. The QA coordinator provides independent review of QC activities and independent performance checks through QA audits.

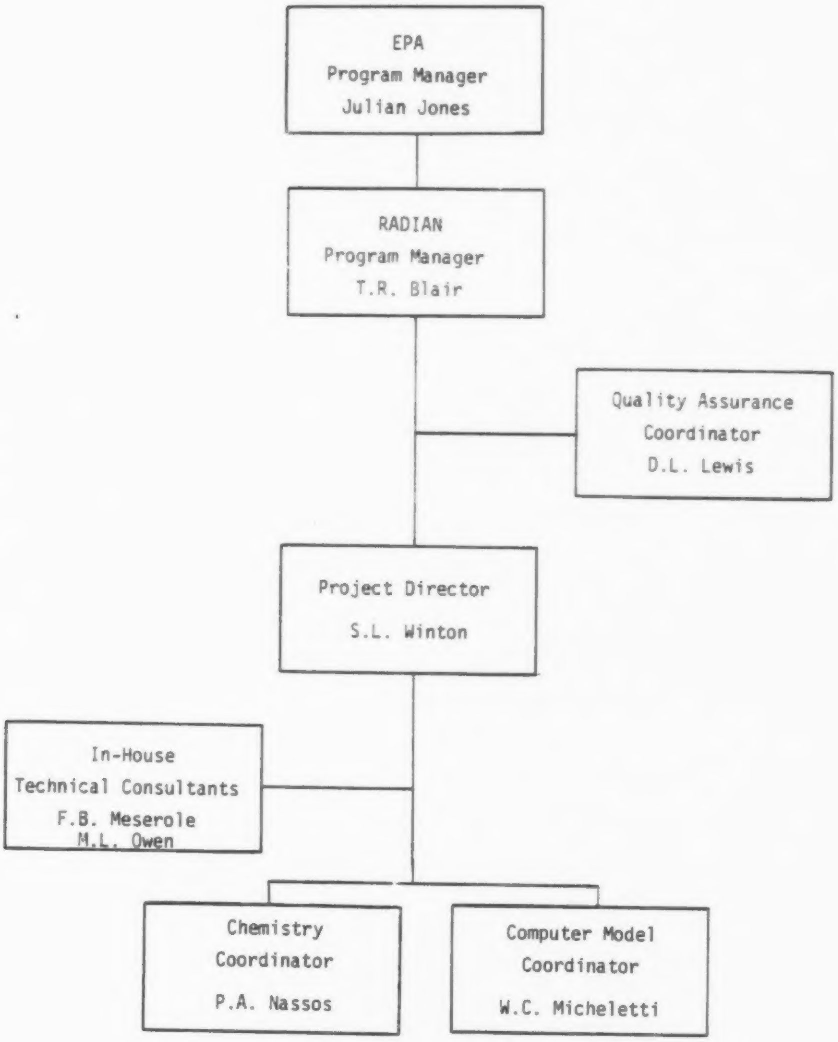

EPA
Program Manager
Julian Jones
RADIAN
Program Manager
T.R. Blair
Quality Assurance
Coordinator
D.L. Lewis
Project Director
S.L. Winton
In-House
Technical Consultants
F.B. Meserole
M.L. Owen
Chemistry
Coordinator
P.A. Nassos
Computer Model
Coordinator
W.C. Micheletti

Figure 2-1. Program Organization

SECTION 3

QUALITY ASSURANCE OBJECTIVES

The objective of the quality assurance efforts for this program is to assess and document the precision and accuracy of technical work performed during sampling and analysis. The QA objectives for precision, accuracy, and completeness for each of the major measurement parameters are summarized in Table 3-1.

TABLE 3-1. ESTIMATED PRECISION, ACCURACY AND DATA CAPTURE OBJECTIVES

Measurement Parameter (Method)	Reference	Experimental Conditions	Precision (Std. Dev.)	Accuracy*	Expected Data Capture
Temperature(Thermometirc)	EPA Method 170.1	Aqueous	1%	±1%	100%
pH (Electrometric)	EPA Method 150.1	Aqueous	3%	±1%	95%
Conductivity (Electrometric)	EPA Method 120.1	Aqueous	6%	±5%	95%
Total Dissolved Solids (Gravimetric)	EPA Method 160.1	Aqueous	5%	±10%	95%
Total Suspended Solids (Gravimetric)	EPA Method 160.2	Aqueous	5%	±10%	95%
Hardness (Titrimetric)	EPA Method 130.2	Aqueous	3%	±5%	95%
Alkalinity (Titrimetric)	EPA Method 310.1	Aqueous	5%	±10%	95%
Phosphate, Ortho (Colorimetric)	EPA Method 365.2	Aqueous	5%	±4%	90%
Phosphate, Total (Colorimetric)	EPA Method 365.2	Aqueous	5%	±4%	95%
Silica (Colorimetric)	EPA Method 370.1	Aqueous	8%	±7%	90%
Calcium (Titrimetric)	EPA Method 215.2	Aqueous	3%	±3%	95%
Calcium (Atomic Absorption)	EPA Method 215.1	Aqueous	2%	±5%	95%
Magnesium(Atomic Abosrption)	EPA Method 242.1	Aqueous	4%	±5%	95%
Potassium (Atomic Absorption)	EPA Method 258.1	Aqueous	5%	±5%	95%
Sodium (Atomic Absorption)	EPA Method 273.1	Aqueous	2%	±5%	95%
Silicon (Atomic Absorption)	-	Aqueous	2%	±5%	95%
Fluoride (Ion Chromatography)	-	Aqueous	5%	±5%	95%
Chloride (Ion Chromatography)	-	Aqueous	3%	±5%	95%
Nitrate (Ion Chromatography)	-	Aqueous	3%	±5%	95%
Sulfate (Ion Chromatography)	-	Aqueous	3%	±5%	95%

*Expected Range for Bias of Method.

SECTION 4

SAMPLING PROCEDURES

The ash sluice pilot unit consists of six portable skid-mounted equipment module and one control/laboratory building. The pilot unit consists of four basic segments:

- a makeup/recycle tank, a fly ash storage bin and feeder, and a fly ash mixing tank to duplicate the slurrying process;
- a treatment reaction tank to allow additional mixing time prior to sluicing;
- a filter press to simulate the ash pond; and
- an acid feed system and a softener/clarifier to treat recycle water for the prevention/control of scale formation.

An overall flow scheme of the pilot unit is presented in Figure 4-1.

In addition to the basic equipment modules, a test loop assembly is included to monitor the scaling and corrosion effects in the sluice water recycle line. The test loop assembly will consist of two 5.1-cm (nominal 2-inch) diameter schedule 40 stainless steel pipe spools mounted in a parallel configuration. The spools will be identical 0.9 meter (3.0 foot) lengths, flanged for easy removal. The spools will be heat traced and insulated in order to maintain a well temperature of 49°C (120°C). The parallel configuration is valved such that a spool can be easily removed for visual inspection.

FIELD TEST APPROACH

Pilot unit field testing at Plant 9991 will focus on determining the technical feasibility of operating a closed-loop recirculating fly ash sluice water system and obtaining steady-state process and analytical data for verification of the ash sluice computer model. Three levels of recycle water treatment will be investigated:

- no treatment,
- pH adjustment, and
- sidestream softening a portion or all of the recycle water combined with pH adjustment.

For each level of treatment, a constant sluice water flow rate of 50 gpm will be maintained to the mix tank. Fly ash will be added to form a slurry containing either 5.0 or 10.0 weight percent solids.

In an effort to determine the technical feasibility of operating a closed-loop fly ash sluice system, the limiting operating conditions must be identified. This will be accomplished by determining the minimum blowdown achievable without scaling in the recycle line for each of the three levels of treatment. For each test the minimum blowdown will be designated by the point at which the limiting species ($CaCO_3$ or $CaSO_4 \cdot 2H_2O$) becomes supersaturated (relative saturation >1.0) in the recycle stream. This approach is based on the assumption that scale would eventually form in the system if the limiting species remained supersaturated in the recycle line.

To determine whether or not a sample is actually supersaturated, the sample is allowed to equilibrate with seed crystals of the species in question. If the weight of the crystals increase, the sample was supersaturated with respect to that species. If the weight decreases, the sample was subsaturated. This procedure will be used in the field to determine the point at which the limiting species becomes supersaturated in the recycle line.

The basic approach for each test will be to use the ash sluice water computer model to establish initial pilot unit operating conditions until steady state is achieved. At that time, a sample of the recycle stream will be equilibrated with seed crystals of the limiting species ($CaCO_3$ or $CaSO_4 \cdot 2H_2O$). If this procedure indicates that the limiting species is supersaturated, the computer model will be used to estimate new operating conditions (reduced blowdown and increased recycle) and the test will continue at the new operating conditions until supersaturation is attained.

At the conclusion of each steady-state operating period, the test loop assembly and recycle tank will be inspected. Any solids that were deposited during the test will be collected for analysis.

SAMPLING STRATEGY

During the course of field testing, two types of samples will be required. First, samples must be taken periodically to monitor the pilot unit for process upsets and to determine when steady-state operation is achieved. Second, during steady-state operation, samples must be taken to characterize the system. In order to reduce the impact of process water loss due to sampling for operation at low blowdown flow rates, these samples will be kept to a minimum and will be taken from blowdown streams whenever possible.

A list of the samples and other operating parameters used to monitor the pilot unit for steady-stae operation are presented in Table 4-1.

The frequency of these samples will be dependent upon both the system volume for the particular test and the blowdown flow rate. During testing without treatment, a large blowdown flow rate (>40 gpm) will probably be required. For a pilot unit volume of approximately 800 gallons the system will turn over three times in one hour. Therefore, sampling will take place approximately every hour. For lower blowdown flow rates, the frequency of sampling will be reduced to approximately the period required for the system to turn over three times (estimated at four hours for a blowdown of 10 gpm). Because of the increased system volume during sidestream softening and the anticipated reduction in the blowdown flow rate, sampling during sidestream softening tests will be required only two times a day.

TABLE 4-1. PARAMETERS TO MONITOR FOR STEADY-STATE OPERATION

Sample Point and Parameter		Minumum Blowdown Without Treatment	Minimum Blowdown With Acid Addition	Minimum Blowdown With Softening
5-1	System Blowdown			
	Ca	✓	✓	✓
	Na	✓	✓	✓
	pH	✓	✓	✓
	Flow Rate	✓	✓	✓
5-2	Makeup Water			
	Flow Rate	✓	✓	✓
5-4	Mix Tank Outlet			
	Ca	✓	✓	✓
	Na	✓	✓	✓
	pH	✓	✓	✓
5-8	Filter Press Outlet			
	Ca		✓	✓
	Na		✓	✓
	Alkalinity		✓	✓
	pH		✓	✓
5-10	Softener Outlet			
	Ca			✓
	Na			✓
	Alkalinity			✓
	pH			✓
	Flow			✓
5-11	Acid Tank			
	Cl[1] or SO_4[1]		✓	✓
	Flow		✓	✓
5-12	Lime Tank			
	Ca[1]			✓
	Wt.% Solids[1]			✓
	pH[1]			✓
	Flow			✓
5-13	Soda Ash Tank			
	Na[1]			✓
	Alkalinity[1]			✓
	pH[1]			✓
	Flow			✓

---

[1] Per batch basis.

When the parameters listed in Table 4-1 show no significant variation ($\pm 5\%$) over two sample periods, the pilot unit will be considered to be operating at steady state. At this time, a complete set of system characterization samples will be taken. These samples are listed in Table 4-2. Each sample will be 500 ml in volume; 100 ml for analysis of major cations (Ca, Mg, Na, K), 100 ml for analysis of major anions (Cl, SO_4, SiO_2), 50 ml for carbonate analysis, and 250 ml which will be appropriately preserved in case additional analyses are required. In addition, a 200 ml sample of the recirculating water will be taken for equilibration with either $CaCO_3$ or $CaSO_4 \cdot 2H_2O$ seed crystals to determine the relative saturation of the species in the recycle water.

SAMPLING TECHNIQUE

When sampling the pilot unit and the host station's sluicing system, one set of sample bottles will be used for each sample point. This will avoid contamination of good quality streams from bottles previously used to sample contaminated water. After collection, each bottle will be washed with a brush to remove debris and rinsed with deionized water before the next sample is collected. More than one bottle will be required for certain sample situations.

The following sampling techniques will be used for all sample points:

- Open sample line valve full open to flush debris from the line for about 60 seconds.
- If necessary on fast flowing samples, adjust the valve to reduce the flow and allow to run another 60 seconds, or longer, to purge the valve and line.
- Without disturbing the valve, fill the bottle half full and cap, shake, and pour out the contents.
- Fill the bottle to overflowing, rinse the cap, close the bottle and take the sample to the laboratory without delay for processing and analysis.

TABLE 4-2. SAMPLES FOR PILOT UNIT SYSTEM CHARACTERIZATION

Sample Point ID	Sample Point Location	No Treatment	Acid Addition	Softening
S-1	System Blowdown	✓	✓	✓
S-2	Makeup Water	✓	✓	✓
S-3	Mixing Tank Inlet Water	✓	✓	✓
S-4	Mixing Tank Effluent	✓	✓	✓
S-7	Filter Press Solids	✓	✓	✓
S-8	Filter Press Effluent	✓	✓	✓
S-9	Softener/Clarifier Solids			✓
S-10	Softener/Clarifier Effluent			✓
S-11	Recirculation Tank Inlet			✓

- When collecting samples from the recirculating water loop and the sidestream system, except blowdown, use a clean bucket to collect the flush and purge water drained from sample points. After the sample is collected, return this water to the respective system. Loss of the sample line flush water would represent excessive blowdown from either system.

SAMPLE PROCESSING

Once the sample is returned to the laboratory, the following procedure should be followed to prepare the sample for analysis:

- Assign a sample identification code to the sample. The sample code should contain the date and time the sample was collected, test number, and sample collection point.
- Log the sample into the master sample log. An example of the master sample log book appears in Figure 4-2.
- Determine the pH and temperature of the sample.
- Filter a portion of the sample.
- Preserve aliquots of the sample for each specific analysis. Table 4-3 presents specific preservation procedures for each analysis.
- Proceed with the analysis of the processed sample. Table 4-3 also presents the analytical procedures that will be utilized for chemical characterization of the samples.

DATA HANDLING AND PRESENTATION

Data sheets have been developed by Radian for the presentation of both liquid and solid phase analysis. These summary sheets have been designed to organize the data in a clear and logical manner. They are divided into various sections including a section for sample identification (location, date, time, test number, etc.) and a section for analytical results. The liquid phase data sheet is presented in Figure 4-3, while the solid phase data sheet is presented in Figure 4-4.

TABLE 4-3. PRESERVATION AND ANALYTICAL REQUIREMENTS FOR CHEMICAL MEASUREMENTS

Parameter Liquid Phase	Preservation Technique	Analytical Technique
pH	-	Potentiometric
Temperature	-	Thermometric
Total Dissolved Solids	-	Gravimetric
Total Suspended Solids	-	Gravimetric
Conductivity	-	Wheatstone Bridge
Calcium	Diluted Filtrate[1]	Titrimetric
Calcium	Diluted Filtrate[1]	Atomic Absorption
Magnesium	Diluted Filtrate[1]	Atomic Absorption
Sodium	Diluted Filtrate[1]	Atomic Absorption
Potassium	Diluted Filtrate[1]	Atomic Absorption
Alkalinity, Total and phenolpthalien	-	Titrimetric
Fluoride	Diluted Filtrate	Ion Chromatography
Chloride	Diluted Filtrate	Ion Chromatography
Sulfate	Diluted Filtrate	Ion Chromatography
Nitrate	Diluted Filtrate	Ion Chromatography
Phosphate, Total and Ortho	Diluted Filtrate	Spectrophotometric
Silica	Diluted Filtrate	Spectrophotometric
Solid Phase		
Weight Percent Solids	-	Gravimetric
Calcium	Dry Solids	Acid Digestion, Atomic Absorption
Magnesium	Dry Solids	Acid Digestion, Atomic Absorption
Carbonate	Dry Solids	Acid Digestion, Non-dispersive-infrared
Sulfate	Dry Solids	Acid Digestion Ion Chromatography
Silicon	Dry Solids	$LiBO_3$ Fusion, Atomic Absorption

---

[1] Samples preserved by acidification to pH <2 for long term storage (>one day)

											Liquid Phase Analyses																	Solid Phase Analyses								
Radian #	Sample Code	Sample Type	Temp. °C	pH	Specific Gravity	Weight 1	Weight 2	Weight 3	Sample Weight	Dilution Factor	TSS	TDS	Cond.	Hard.	Alk.	Ca	Mg	Na	K	F	Cl	NO_3	SO_4	PO_4	SiO_2	Cl_2	Other	Acid Diss.	Fusion	Ca	Mg	SO_4	CO_3	Si	%Inerts	Comments

Figure 4-2. Master Sample Log

LIQUID PHASE ANALYSIS SUMMARY

Radian #	Sample Location	Date	Time	Test #	Sample #	Stream #	Temp	pH	TSS	TDS	Cond.	Total Hardness	Ca	Mg	Na	K
--		MMDD	HHMM	--	--	--	°C	--	mg/l	mg/l	μmho	mg/l as $CaCo_3$	mg/l	mg/l	mg/l	mg/l

Figure 4-3. Liquid Phase Analysis Summary

LIQUID PHASE ANALYSIS SUMMARY (continued)

Radian #	P ALK	M ALK	Free CO_2	F	Cl	NO_3	SO_4	PO_4	SiO_2	Free Cl_2	Comments
--	mg/l as $CaCO_3$	mg/l as $CaCO_3$	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	

Figure 4-3 (continued)

SOLID PHASE ANALYSIS SUMMARY

Radian #	Sample Location	Date	Time	Test #	Sample #	Stream #	Wt % Solids	Ca	Mg	CO_3	SO_4	Si	Inerts	Comments
--		MMDD	HHMM	--	--	--	%	μg/g	μg/g	μg/g	μg/g	μg/g	%	

Figure 4-4. Solid Phase Analysis Summary

SECTION 5

SAMPLE CUSTODY

Chain of custody procedures will be simplified for this project by providing for on-site analysis of most samples.

FIELD SAMPLING OPERATION

Following sample collection, all samples will be given a unique sample identification code containing date and time the sample was collected, test number, and sample location. After assigning a sample code, the sample will be logged into a master sample log book (see Figure 4-2).

LABORATORY OPERATION

The lead chemist will coordinate the on-site measurement and analyses. Samples will be dispersed for analysis by the lead chemist to the designated analyst. Analysts will follow accepted laboratory procedures while handling all samples. Procedures and results of each analysis will be documented by the analyst in a bound notebook.

Examples of notebook arrangements for each specific analysis are illustrated below.

pH and Temperature

The pH and temperature of the samples collected will be recorded in the master sample log book (see Figure 4-2).

Total Suspended Solids

			C	B	A		
Radian Number	Analysis Date	Sample Code	Sample Volume (liter)	Filter Weight*	Filter + Solids Weight*	Solids Weight*	$\frac{(A-B) \times 1000}{C}$ = mg/l TSS

*All weights in grams.

Total Dissolved Solids

			C	B	A		
Radian Number	Analysis Date	Sample Code	Sample Volume (liter)	Dish Weight*	Dish + Residue Weight*	Residue Weight*	$\frac{(A-B) \times 1000}{C}$ = mg/l TDS

*All weights in grams.

Specific Gravity

			A	B		C	
Radian Number	Analysis Date	Sample Code	Bottle Weight	Bottle + Sample Weight*	Sample Weight*	Sample Volume ml	$\frac{(B - A)}{C}$ Specific Gravity

*All weights in grams.

Conductivity

			t	R	
Radian Number	Analysis Date	Sample Code	Sample Temperature °C	Sample Conductance mhos	Corrected Conductance

Hardness or Calcium

			C			A	B	
Radian #	Analysis Date	Sample Code	Sample Volume (ml)	Initial Buret Volume	Final Buret Volume	ml Titrant Used	Titrant Equivalence	$\frac{A \times B \times 1000}{C}$ mg/l

Alkalinity

			C	A		B		N	
Radian #	Analysis Date	Sample Code	Sample Volume (ml)	Volume (ml) Titrant to P Endpoint	P Alkalinity mg/L $CaCO_3$	Volume (ml) Titrant to M Endpoint	M Alkalinity mg/l $CaCO_3$	Titrant Normality	Sample pH

Atomic Absorption

Radian Number	Analysis Date	Sample Code	Element	Absorbance	mg/l	Bottle Dilution Factor	Analysis Dilution Factor	mg/l

Ion Chromatography

Radian Number	Analysis Date	Sample Code	Species	Peak Height	mmole/l Injected	Analysis Dilution Factor	Bottle Dilution Factor	Final mmole/l

Phosphate, Total or Ortho

Radian #	Analysis Date	Sample Code	Sample Volume (ml)	Absorbance	mg/l-P	Analytical Dilution Factor	Final mg/l-P	Final mg/l-PO_4

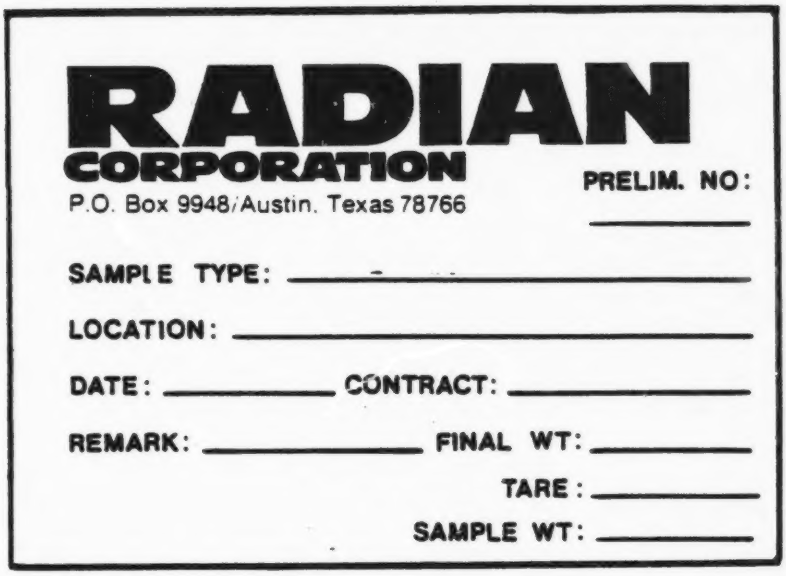
Silica

Radian #	Analysis Date	Sample Code	Sample Volume (ml)	Absorbance	mg/l-SiO_2	Analytical Dilution Factor	mg/l-SiO_2

SAMPLE HANDLING

Samples that are sent back to Austin for off-site analysis will be handled in the following manner:

- Liquid level of transported samples will be marked on the bottle.
- Container cap will be taped closed.
- Sample labels (Figure 5-1) and chain-of-custody seals (Figure 5-2) will be completed and affixed to the sample container.
- Chain-of-custody forms (Figure 5-3) will be completed by any personnel included in the sample handling.



RADIAN
CORPORATION
P.O. Box 9948/Austin. Texas 78766

PRELIM. NO: ____________

SAMPLE TYPE: ________________________________

LOCATION: ________________________________

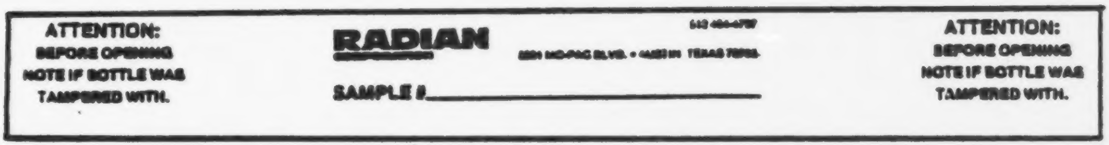
DATE: ____________ **CONTRACT:** ____________

REMARK: ____________ **FINAL WT:** ____________

TARE: ____________

SAMPLE WT: ____________

Figure 5-1. Example of Radian Sample Bottle Label



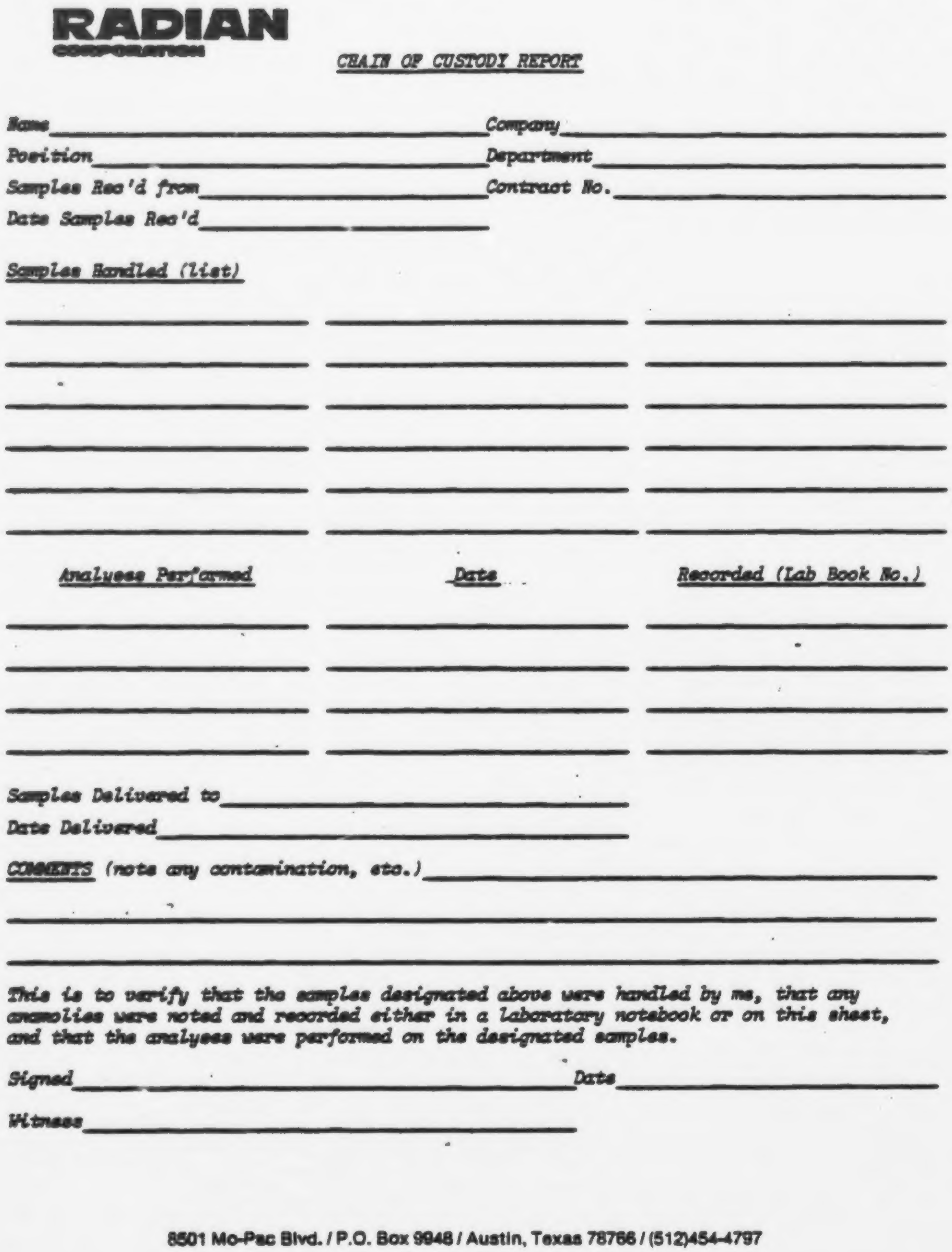
ATTENTION:
BEFORE OPENING
NOTE IF BOTTLE WAS
TAMPERED WITH.

RADIAN

SAMPLE #______________________________

ATTENTION:
BEFORE OPENING
NOTE IF BOTTLE WAS
TAMPERED WITH.

Figure 5-2. Example of the Chain of Custody Seal Used to Seal Sample Bottle Lids



RADIAN
CORPORATION

CHAIN OF CUSTODY REPORT

Name *Company*
Position *Department*
Samples Rec'd from *Contract No.*
Date Samples Rec'd

Samples Handled (list)

Analyses Performed	*Date*	*Recorded (Lab Book No.)*

Samples Delivered to
Date Delivered
COMMENTS (note any contamination, etc.)

This is to verify that the samples designated above were handled by me, that any anomolies were noted and recorded either in a laboratory notebook or on this sheet, and that the analyses were performed on the designated samples.

Signed *Date*
Witness

8501 Mo-Pac Blvd. / P.O. Box 9948 / Austin, Texas 78766 / (512)454-4797

Figure 5-3. Chain of Custody Report

SECTION 6

ANALYTICAL PROCEDURES

In order to meet the goals of this program, some or all of the following liquid phase parameters will be measured in samples collected from the test unit: pH, temperature, conductivity, total dissolved solids, total suspended solids, hardness, alkalinity, orthophosphate, total phosphate, silica, calcium, magnesium, sodium, potassium, fluoride, chloride, nitrate, and sulfate.

The various parameters to be measured and analytical methodologies are listed in Table 6-1. The associated accuracy, reproducibility, and detection limits of each analytical procedure are presented in Table 6-2.

Each of the selected analytical methods are briefly described in this section of the QA project plan.

pH

The pH of a sample will be determined electrometrically using either a glass electrode in combination with a reference potential electrode or a combination pH-reference electrode. Prior to use, the pH meter is calibrated with at least two buffer solutions whose pH bracket sample pH.

TEMPERATURE

Temperature measurements will be made using a mercury-in-glass celcius thermometer.

TABLE 6-1. ANALYSIS PARAMETERS AND METHODOLOGY

Parameter to be Measured	Methodology
Temperature	EPA Method 170.1
pH	EPA Method 150.1
Conductivity	EPA Method 120.1
Total Dissolved Solids	EPA Method 160.1
Total Suspended Solids	EPA Method 130.1
Alkalinity	EPA Method 310.1
Phosphate, total and ortho	EPA Method 365.2
Silica	EPA Method 370.1
Calcium	EPA Method 215.1
Calcium (EDTA Titrimetric)	EPA Method 215.2
Magnesium	EPA Method 242.1
Potassium	EPA Method 258.1
Sodium	EPA Method 273.1
Fluoride	Ion Chromatography
Chloride	Ion Chromatography
Nitrate	Ion Chromatography
Sulfate	Ion Chromatograpjy

TABLE 6-2. ESTIMATED ACCURACY, PRECISION, AND DETECTION LIMITS FOR THE SELECTED ANALYTICAL METHODS

Measurement Parameter (Method)	Precision (Std.Dev.)	Accuracy	Detection Limit
Temperature (Thermometric)	1%	±1%	---
pH (Electrometric)	3%	±1%	---
Conductivity (Electrometric)	6%	±5%	10 μmhos
Total Dissolved Solids (Gravimetric)	5%	±10%	1.0mg/l
Total Suspended Solids (Gravimetric)	5%	±10%	1.0mg/l
Hardness (Titrimetric)	3%	±5%	5.0mg/l as $CaCO_3$
Alkalinity (titrimetric)	5%	±10%	5.0mg/l as $CaCO_3$
Phosphate (Colorimetric)	5%	±4%	.01mg/l as PO_4-P
Phosphate, Total (Colorimetirc)	5%	±4%	.01mg/l as PO_4-P
Silica (Colorimetric)	8%	±7%	1.00mg/l as SiO_2
Calcium (Titrimetric)	3%	±5%	5.0mg/l as Ca
Calcium (Atomic Absorption)	2%	±5%	0.40mg/l as Ca
Magnesium (Atomic Absorption)	4%	±5%	0.40mg/l as Mg
Potassium (Atomic Absorption)	5%	±5%	0.20mg/l as K
Sodium (Atomic Absorption)	2%	±5%	0.10mg/l as Na
Silicon (Atomic Absorption)	5%	±5%	20.0mg/l as Si
Fluoride (Ion Chromatorgraphy)	3%	±5%	0.10mg/l as F
Chloride (Ion Chromatography)	3%	±5%	0.20mg/l as Cl
Nitrate (Ion Chromatography)	3%	±5%	0.40mg/l as NO_3
Sulfate (Ion Chromatography)	3%	±5%	0.40mb/l as SO_4

TOTAL SUSPENDED SOLIDS (TSS)

TSS will be determined by a gravimetric procedure in which an aliquot of sample is filtered through a tared fine glass fiber filter. The filter and retained solids will be dried at 103° to 105°C, and the mass of the solids determined by weighing.

TOTAL DISSOLVED SOLIDS

TDS will be determined by a gravimetric method in which a portion of a sample is filtered through a fine glass fiber filter. A measured aliquot of the filtrate will be placed in a tared container and evaporated to dryness at 105°C. The mass of the residue will be determined by weighing.

ALKALINITY

Alkalinity will be determined by titration using a dilute sulfuric acid standard to successive bicarbonate and carbonic acid equivalence points.

Phenolphthalein indicator will be used to determine that fraction of alkalinity contributed by the hydroxide and half the carbonate. Indicators responding in the pH range of 4 to 5 will be used to determine the alkalinity contributed by hydroxide, carbonate, and bicarbonate. Alkalinity can also be determined potentiometrically employing a pH meter and titrating to a specific inflection point.

HARDNESS

Hardness is an indication of the total amount of polyvalent cations, primarily calcium and magnesium, present in a sample. However, other cations such as aluminum, iron, manganese, strontium, and zinc can also contribute to the hardness of a sample.

Calcium and magnesium hardness will be determined by titrating the sample with disodium ethylenediamine tetracetate (Na_2EDTA) which acts as a sequestering agent. The endpoint of the reaction is detected by means of Eriochrome Black T indicator, which has a red color in the presence of calcium and magnesium and a blue color when the cations are sequestered.

CONDUCTIVITY

Conductivity is a numerical expression of the ability of a water sample to carry an electrical current. This number depends on the total concentration of the ionized substances dissolved in the water and the temperature at which the measurement is made. The conductance of a sample, expressed in mhos (reciprocal of ohms), will be measured with a conductivity meter and a platinized conductivity cell.

PHOSPHATE, ORTHO- AND TOTAL

The ascorbic acid method will be used in the determination of phosphate. In this method, available orthophosphate reacts with ammonium molybdate and potassium tartrate in an acidic medium to form a heteropoly acid, phosphomolybdic acid. The phosphomolybdic acid in turn is reduced by ascorbic acid to a highly colored molybdenum blue. The absorbance of the colored sample will then be measured at 880 nm and compred to a set of standards. Total phosphate determination requires a preliminary sulfuric acid-ammonium persulfate digestion to hydralyze organically bound phosphate and polyphosphates to the soluble orthophosphate form.

The molybdosilicate method will be used in the determination of silica. In this method, ammonium molybdate reacts with silica and any phosphate in an acidic medium to produce heteropoly acids. Oxalic acid is added to destroy the molybdophosphoric acid but not the molybdosilicic acid. After color development, the absorbence of the colored sample will be measured at 410 nm and compared to a set of standards.

ATOMIC ABSORPTION

Atomic absorption will be utilized in the determination of calcium, magnesium, potassium, sodium, and silicon. Atomic absorption involves aspirating a liquid sample into an air-acetylene flame where it is vaporized and atomized. Radiation from an appropriate hollow cathode lamp is passed through the flame. Non-absorbed radiation then passes through a monochromator, to a detector, and finally to a digital readout or strip chart recorder. The output for unknown samples will be compared to standards of known concentration to obtain sample concentrations.

ION CHROMATOGRAPHY

Ion chromatography will be utilized in the determination of fluoride, chloride, nitrate, and sulfate.

Ion chromatography combines the techniques of ion exchange, liquid chromatography, and conductometric detection for the determination of aqueous ionic species.

A sample is injected into the instrument by means of a 0.1 ml sample loop and is eluted through a system of two ion exchange columns and a conductivity cell. The first column separates the ions in the sample. Each different ion has a characteristic retention time in the column for a given set of conditions. The second column removes the eluent ions, thus minimizing the background conductivity of the eluent. Finally, the conductivity cell is used to determine the concentration of ions in the sample.

By comparing the sample ions retention times to retention times of known ion standards, specific ions are identified. Standard ion solutions of known concentrations will be run to obtain a calibration curve of peak height (from a strip chart recorder) versus concentration. Then the peak heights of the samples will be compared to the standard curve to obtain sample concentrations.

ACID DISSOLUTION

Acid dissolutions will be performed on dry solids to determine their major soluble constituents (Ca, Mg, and SO_4). It will involve the addition of a known mass of solids to an acidic solution and allowing it to stir for 45 minutes; after which the mixture will be filtered, the resulting solution analyzed, and the acid insoluble fraction measured.

LITHIUM BORATE FUSION

Lithium borate fusions will be performed on dry solids to determine silica concentration. This involves mixing a known mass of sample with $LiBO_3$ and fusing at 1,050°C in a muffle furnace. The resulting fusion will then be dissolved in 5% HCl and analyzed for Si by atomic absorption.

CALCIUM (TITRATION)

A simple and rapid alternate method to determine calcium concentration is by titration with EDTA. In this procedure, the calcium is determined directly using EDTA, when the pH is made sufficiently high that the magnesium is largely precipitated as the hydroxide and an indicator is used that combines only with calcium. Murexide, for example, changes from pink to purple when all calcium has been complexed by EDTA.

SECTION 7

CALIBRATION PROCEDURES

This section presents information on the calibration of analytical systems. Included is a description of the calibration procedures, calibration frequency, and the calibration standards to be used. Table 7-1 summarizes the analytical calibration requirements for the program.

ANALYTICAL BALANCE CALIBRATION

Analytical balances will be calibrated over the expected range of use with standard weights (NBS Class S). Measured values must agree within ±0.1 mg. The balances will be calibrated prior to the field measurement program.

Field checks of balance accuracy will be made monthly using a set of weights which have previously been weighed side-by-side with the NBS traceable weights. The balance calibration data sheet is illustrated in Figure 7-1.

ATOMIC ABSORPTION

The GBC Model SB900 atomic absorption unit will be calibrated for each sample set analyzed by introducing different concentrations of each species into the instrument. Calibration standards will be prepared from certified standards. A minimum of three concentrations of each species will be used to generate a calibration curve by the method of Least Squares Fit of Data (linear regression). The calibration will be considered acceptable if the correlation coefficient is greater than 0.9950.

TABLE 7-1. SUMMARY OF ANALYTICAL CALIBRATION REQUIREMENTS

Parameter	Analytical Method	Type of Calibration	Frequency	Acceptance Criteria
Cations	Atomic Absorption	Multipoint	2/Sample Set	Correlation Coefficient ⩾0.9950
Anions	Ion Chromatography	Multipoint	2/Sample Set	Correlation Coefficient ⩾0.9950
Phosphate	Spectrophotometric	Multipoint	1/Sample Set	Correlation Coefficient ⩾0.9950
Silica	Spectrophotometric	Multipoint	1/Sample Set	Correlation Coefficient ⩾0.9950
pH	Potentiometric	Multipoint	1/Sample Set	Agreement within ±0.1 pH
Conductivity	Conductimetric	Single Point	1/Sample Set	Agreement within ±50 μmhos
Total Suspended Solids	Gravimetric	Analytical Balance Multipoint, NBS Traceable Weights	1/week	Accurate within ±0.1 mg
Total Dissolved Solids	Gravimetric	Analytical Balance Multipoint, NBS Traceable Weights	1/week	Accurate within ±0.1 mg

ANALYTICAL BALANCE FORM

MODEL________________ IDENTIFICATION NO.________________

CLASSIFICATION OF STANDARD WEIGHTS________________

	0.5000 g	1.0000 g	10.0000 g	50.0000 g	100.000 g
Date					
Analyst					
Measured Weight					
Reference Weight					
Deviation					
% Deviation* (from Reference Weight)					
Date					
Analyst					
Measured Weight					
Reference Weight					
Deviation					
% Deviation* (from Reference Weight)					

$$* \text{ Deviation} = \frac{\text{Deviation}}{\text{Reference Weight}} \times 100\%$$

Figure 7-1. Balance Calibration Data Sheet

ION CHROMATOGRAPHY

The Dionex Model 10 ion chromatograph will be calibrated for each sample set analyzed. This will be accomplished by introducing different concentrations of each species into the instrument. Calibration standards will be prepared from certified standards. A minimum of three concentrations of each species will be used to generate a calibration curve by the method of Least Squares Fit of Data (linear regression). The calibration curve will be considered acceptable if the correlation coefficient is greater than 0.9950.

SPECTROPHOTOMETRIC

The Spectronic Model 21 spectrophotometer will be calibrated for each sample set analyzed. This will be accomplished by introducing different concentrations of each species into the instrument. Calibration standards will be prepared from certified standards. A minimum of five concentrations of each species will be used to generate a calibration curve by the method of Least Squares Fit of Data (linear regression). The calibration will be considered acceptable if the correlation coefficient is greater than 0.9950.

pH

The Orion Model 701A pH meter will be calibrated for each sample set analyzed. This will be accomplished by calibrating the meter with two certified pH buffers that bracket the sample's pH. After calibration, agreement between the pH meter and the certified buffer must be ±0.1 pH unit.

CONDUCTIVITY

The YSI Model 31 conductivity meter's performance will be checked for each sample set analyzed. This will be accomplished by checking the meter's reading for a certified KCl solution. The meter's output should agree within ±50 μmhos of the standard solution's conductivity.

SECTION 8

DATA REDUCTION, VALIDATION, AND REPORTING

Mr. W.C. Micheletti will serve as Task Leader for all data processing including validation. Mr. Micheletti will also be responsible for the reporting of data.

The lead chemist on-site will coordinate daily QC activities including record keeping, data processing, and assessment of data validity. The data reduction process for all phases of the analytical work will be standardized by the use of preformatted laboratory notebooks. Notebook formats for each type of analysis are illustrated in Section 5. Each notebook format is tailored to a specific type of analysis and provides a concise, logical progression of data reduction, retaining important intermediate values for validation purposes.

The program objectives necessitate rapid sample turnaround and daily summaries of analytical results. The lead chemist on-site will be responsible for validation and tabulation of analytical data on a daily basis. Preformatted data sheets for analytical results (Figures 4-3 and 4-4) will be used to facilitate this task and will expedite the transfer of data to the on-site engineer. All data will be validated based upon representative process conditions during sampling, acceptable sample collection and/or preservation procedures, consistency with other and/or expected results, and adherence to prescribed analytical QC procedures. Any suspect data will be flagged and identified with respect to the nature of the problem with validity.

SECTION 9

INTERNAL QUALITY CONTROL CHECKS

Daily QC procedures will insure the continuous production of useful and valid data throughout the course of the program.

SAMPLING QUALITY CONTROL PROCEDURES

The QC checks and procedures which assure data quality are an integral part of the sampling and analytical scheme. Often the most applicable QC check is simply strict adherence to the prescribed procedure. The most important sampling procedures, with respect to data quality, are summarized below.

- A single set of sample bottles will be used for each sampling point to avoid cross-stream contamination of samples.
- Samples will be collected only after the sample line and valve are thoroughly flushed.
- Sample collection bottles will be thoroughly cleaned before reuse.
- Samples will be logged into the master log book immediately after collection. This log book format (Figure 4-2) provides a checklist whereby the required analyses are immediately identified so that preservation procedures may be implemented as necessary.
- The lead chemist will review the master log book on a daily basis to insure that all required samples have been collected and required analyses performed.

ANALYTICAL QUALITY CONTROL PROCEDURES

All analyses performed in support of the program will be done using proper grades of reagents and accepted laboratory procedures. Adherence to prescribed QC procedures will insure consistent data quality. These QC procedures will focus on the specific aspects of the analyses discussed below. The QC standards which will be analyzed alongside samples are listed in Table 9-1. The frequency of analysis for calibration standards, blanks, QC standards, and duplicates are listed in Table 9-2. The acceptance criteria for QC analyses are presented in Table 9-3. Results of control standard analyses will be tabulated daily and plotted on a control chart for each parameter. An example control chart is illustrated in Figure 9-1. Results of replicate analyses will be tabulated using the form shown in Figure 9-2.

During testing, the parameters used for monitoring system operation and steady-state determination will be plotted on site as an overall QC check. The primary purpose of this activity will be to identify any unusual data points, such as potential analytical error or process upsets, so that they may be verified prior to completion of the test. When steady state has been achieved, the analytical results of the system characterization samples, along with the appropriate process data, will be used to calculate material balances around the mix tank, the filter process and overall system. Again, this activity will be completed on site so that any inconsistencies or problems can be identified and resolved. The equations used for each of these calculations are presented below:

mix tank: $$([X]_{mto} - [X]_{mti})(Q_{mu} + Q_{rc}) = (\chi_{ash})(Q_{ash})(10^6) \quad (3\text{-}2)$$

filter press: $$([X]_{mto})(Q_{mu} + Q_{rc}) = ([X]_{bd})(Q_{rc} + Q_{bd} + Q_{fp}) \quad (3\text{-}3)$$

overall: $$([X]_{mu})(Q_{mu}) + (10^6)(\chi_{ash})(Q_{ash}) = ([X]_{bd})(Q_{bd} + Q_{fp}) \quad (3\text{-}4)$$

where, [X] is the concentration of species X (ppm) in the mix tank inlet (mti), the mix tank outlet (mto), the makeup (mu), and the blowdown (bd),

is the weight fraction of species X leaching from the fly ash, and

TABLE 9-1. SUMMARY OF QUALITY CONTROL SAMPLES

Parameter	Method	Quality Control Samples
Cations	Atomic Absorption	Calcium, Magnesium, Potassium, Sodium, and Silicon - Certified Standards
Anions	Ion Chromatography	Chloride, Fluoride, Sulfate, and Nitrate - Certified Standards
Phosphates	Spectrophotometric	Aqueous KH_2PO_4
Hardness	Titrimetric	Certified Calcium and Magnesium Standards
Alkalinity	Titrimetric	Aqueous Na_2CO_3 and $NaHCO_3$
Silica	Spectrophotometric	Certified Silicon Standards
Conductivity	Electrometric	Aqueous KCl

TABLE 9-2. TYPE AND FREQUENCY OF QUALITY CONTROL ANALYSES

Types of Analysis:	Atomic Absorption (Cations)					Ion Chromatography (Anions)					Titrimetric (Hardness, Alkalinity, Calcium)			Spectro-photometric (SiO_2 and PO_4^-)			Conductivity			pH	Gravimetric (TDS, TSS, dissolution and fusion)
Number of Samples:	1	2-10	11-20	21-40	>40	1	2-10	11-20	21-40	>40	1-10	11-20	>20	1-10	11-20	>20	1-10	11-20	>20		
Calibration Standards (Set)	1/S	1/S	2/S	2/S	2/S	2/S	2/S	2/S	2/S	2/S	N/A	N/A	N/A	1/S	1/S	1/S	N/A	N/A	N/A	2/S	1/W
Blank	1/S	1/S	2/S	2/S	2/S	2/S	2/S	2/S	2/S	2/S	1/S	1/S	1/S	1/S	1/S	1/S	1/S	1/S	1/S	N/A	1/S*
QC Standard	1/S	1/S	2/S	2/S	2/S	1/S	1/S	2/S	2/S	2/S	1/S*	2/S*	2/S*	1/S	1/S	1/S	1/S	2/S	2/S	N/A	1/S*
Duplicate Samples	1/S	1/S	2/S	3/S	10%	1/S	1/S	2/S	3/S	10%	1/S	2/S	3/S	1/S	2/S	3/S	1/S	2/S	3/S	N/A	10%

*Solid dissolutions and $LiBO_2$ fusions only

Key:

S = Set of Samples
D = Day
W = Week
N/A = Not Analyzed

TABLE 9-3. ACCEPTANCE LIMITS FOR QUALITY CONTROL ANALYSES

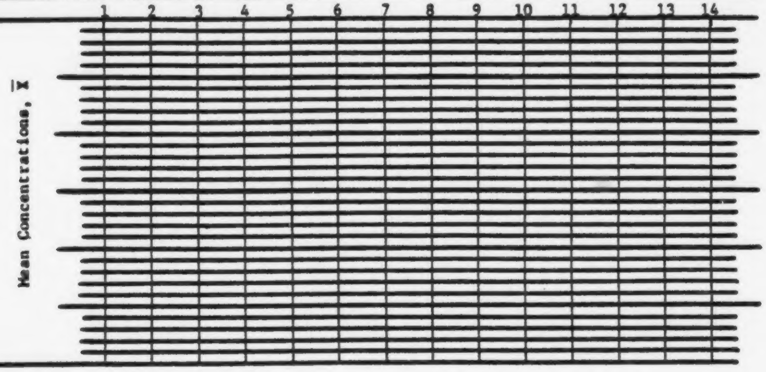
Type of Analysis:	Atomic Absorption (Cations)	Ion Chromatography (Anions)	Titrimetric (Hardness, Alkalinity Calcium)	Spectro-photometric (SiO_2 and PO_4^-)	Conductivity	pH	Gravimetric (TDS, TSS)
Calibration Standards (Set)	Correlation Coefficient >0.9950	Correlation Coefficient >0.9950	N/A	Correlation Coefficient >0.9950	±50 µmhos Agreement	±0.1 pH units Agreement	100 ± 2% Agreement
Blank	N/A	N/A	N/A	N/A	1 µmho	N/A	N/A
QC Standard	100 ± 5% Recovery	100 ± 5% Recovery	100 ± 5% * Recovery	100 ± 10% Recovery	100 ± 5% of Theoretical	N/A	N/A
Duplicate Samples	100 ± 5% Agreement	100 ± 5% Agreement	100 ± 5% Agreement	100 ± 10% Agreement	100 ± 5% Agreement	100 ± 5% Agreement	100 ± 5% Agreement

N/A = Not Applicable

QC STANDARD ANALYSIS RECORD

Contract ____________________ Analyst ____________________
Site ____________________ Analyte Units ____________________
Method/Instrument ____________________

Parameter:															
Date															
Input Conc.															
Measured Conc.	1														
	2														
	3														
Mean Conc.	$\overline{X}$														
CV															



Parameter:															
Date															
Input Conc.															
Measured Conc.	1														
	2														
	3														
Mean Conc.	$\overline{X}$														
CV															

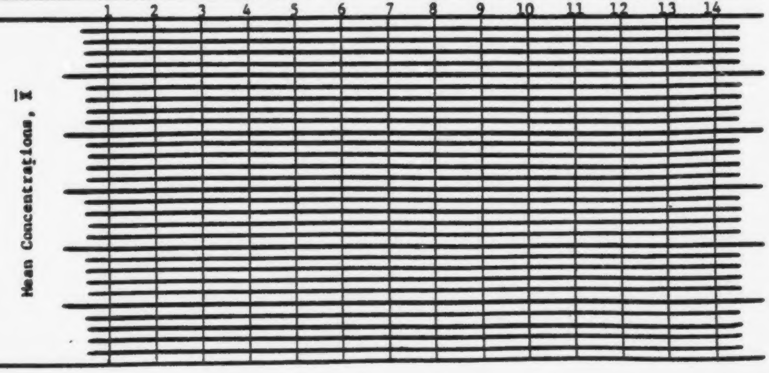


Figure 9-1. Example of QC Standard Analysis Record

REPLICATE ANALYSIS LOG

Contract ______________________
Site ______________________
Method/Instrument ______________________

Analyst ______________________
Analyte Units ______________________

Sample I.D.	Date	Analyte	Analyte	Analyte	Analyte	Analyte	Analyte	Analyte	Analyte	Pooled CVs
	CV									
	CV									
	CV									
	CV									
	CV									
	CV									
	CV									
	Pooled CVs									

Comments ______________________

Figure 9-2. Example of Replicate Analysis Log

Q is the flow rate (lb/min) of the makeup (mu), recycle (rc), ash (ash), and water occluded with solids (fp).

By providing rapid feedback of data evaluation with respect to this, as well as other QC checks, close and careful control of data quality may be maintained. For convenience, the specific analytical quality control checks and procedures are presented according to the major analytical categories. These categories include:

- Physical measurements.
- Titrimetric methods.
- Instrumental methods.
- Solids dissolutions.

Physical Measurements

Physical measurements include the following determinations:

- Temperature,
- pH,
- Conductivity,
- Total suspended solids,
- Total dissolved solids, and
- Specific gravity.

QC procedures for physical measurements will focus on the following:

- Temperature, pH, and conductivity measurements will be made as soon as possible after sample collection.
- Duplicate conductivity mesurements and duplicate weighings for TDS, TSS, and specific gravity will be made as indicated in Table 9-2.
- QC standards will be analyzed as indicated in Table 9-2.

- Blanks (conductivity) will be analyzed as indicated in Table 9-2.

- Notebook entries will be reviewed daily by the lead chemist on-site.

- The pH meter will be standardized using a buffer solution of known pH. The meter response will then be checked using a buffer 3 pH units different from the first. The pH of the buffer solutions will bracket the pH of the sample(s).

- Mercury-in-glass thermometers will be used for temperature measurements. These thermometers will be periodically checked using an ice bath and boiling DI water.

- All samples will be equilibrated to a constant temperature prior to weighing.

- All weighings will be to a constant weight (i.e., weight change between weighings will be $\leq$ 5 mg for the analytical balance and $\leq$50 mg for the top loader).

- Duplicate weighings will be made of 10 percent of the samples weighed during each shift.

- Balances will be checked once per week using specific calibration weights as QC standards.

Titrimetric Methods

Titrimetric methods will be used for the following analyses:

- Hardness,
- M and P alkalinity,
- Calcium

The internal QC procedures for titrimetric methods will include the following:

- Blanks will be analyzed along with samples as indicated in Table 9-2.

- QC standards will be analyzed along with samples as indicated in Table 9-2.

- Duplicate sample analyses will be performed according to Table 9-2.
- Results of duplicate analyses, QC and QC standard analyses will be tabulated daily and plotted on a control chart similar to that in Figure 9-1.
- Hardness titration results will be compared to the calcium and magnesium values obtained by atomic absorption.
- Calcium titration results will be compared to calcium AA results, where possible
- Control charts will be reviewed daily by the lead chemist for acceptability.
- All samples will be analyzed immediately and/or properly preserved and stored.

Instrumental Methods

Analyses which will be performed using instrumental methods, and the applicable methods are summarized below:

- Atomic Absorption Spectroscopy (AA)
  (for Ca, Mg, Na, K, and Si)
- Ion Chromatography (IC)
  (for F, Cl, NO_3, and SO_4), and
- Spectrophotometry (for SiO_2 and ortho- and total phosphate).

All of the instrumental methods employed involve the generation of a standard calibration curve. This curve is a linear plot of analyte concentration versus instrument response (absorbance or conductivity). The calibration curve is generated using response data from analysis of the blanks and calibration standards. This data is plotted mathematically by the method of Least Squares Fit of Data to get the slope, Y-intercept and correlation coefficient of the calibration curve. The validity of the resulting curve may be assessed by examining these three items. The slope of the curve is related to response sensitivity. Any marked deviation from the average slope for the method and/or parameter of interest indicates that a change in sensitivity has occurred. The Y-intercept of the curve should ideally be equal to zero, i.e,. instrument response to a blank should be zero and the calibration curve should pass through the origin.

In practice, the curve rarely passes exactly through the origin. The correlation coefficient is indicative of the linearity of the curve. According to Beer's law, the response should be directly proportional to concentration. Perfect correlation of the X and Y data points is indicated by a correlation coefficient of 1.0. An acceptable calibration curve should have a correlation coefficient no less than 0.9950.

The internal QC checks for the instrumental methods include the following:

- Calibration curves will be generated according to the frequencies indicated in Table 9-2 and evaluated for acceptability as discussed above.
- The QC standards will be analyzed according to the frequency indicated in Table 9-2.
- Blanks will be analyzed for each parameter and will be incorporated into the calibration curves as the X and Y zero points.
- Duplicate samples will be analyzed as indicated in Table 9-2.
- The results of QC standard anlayses and duplicate analyses will be plotted on control charts (Figure 9-1) on a daily basis.
- The acceptability criteria for the calibration curve and QC standard analyses indicated in Table 9-2 must be met before sample analysis may proceed.
- The slope and correlation coefficient of each calibration curve will be tabulated on a daily basis and compared to results from previous days.
- All QC notebook entries will be reviewed each day by the lead chemist on-site.
- All samples not analyzed immediately will be properly preserved and stored.

- Selected samples will be returned to Radian's Austin, Texas, laboratories for analysis, providing interlaboratory comparisons of results.

Solid Dissolutions

Solid phase samples will be prepared for analysis by dissolution. With the exception of determining the insoluble fraction (Section 8, Analytical Procedures), the dissolution of solid samples is a preparatory step in the analytical scheme rather than an analytical method. As such, the QC procedures for the parameters of interest apply. Following the dissolution step, the sample may be treated like any other liquid phase sample with respect to analytical and QC procedures. Additionally, however, certain QC checks will apply specifically to the treatment of the solids. These include the following:

- Duplicate samples will be carried through the entire analytical scheme, i.e., fusion and/or dissolution and analysis according to the frequency in Table 9-2.
- Reagent blanks will be prepared and analyzed along with samples as indicated in Table 9-2.
- Duplicate weighings will be made on 10 percent of the solid phase samples.
- Notebook entries will be reviewed by the lead chemist on a daily basis.
- Selected samples will be returned to Radian's Austin, Texas, laboratories for analysis to provide interlaboratory comparison of results.

SECTION 10

PERFORMANCE AND SYSTEM AUDITS

An audit is an independent assessment of data quality. This independent assessment is achieved by using apparatus and standards that are different from those used by the regular field crew. Routine QA checks are necessary for obtaining good quality data.

Mr. D.L. Lewis, the QA Coordinator, will conduct the quality assurance audits for this project. The systems audit will consist of review and evaluation of the QC data generated during pilot unit testing. This will represent a qualitative assessment of the adequacy and effectiveness of the internal QC system. The performance audit will provide a quantitative evaluation of the accuracy of the analytical efforts. This will be accomplished by submitting audit standards for analysis along with field samples. The audit standards which will be used for this program will be EPA Mineral/Physical Analyses Quality Control samples obtained through the EPA Quality Assurance Branch (QAB), Environmental Monitoring and Support Laboratory (EMSL), Cincinnati, Ohio. Each of the parameters listed in Table 10-1 will be audited at two levels. Audit samples will be submitted for blind analysis and the results will be reported to the QA coordinator for evaluation.

TABLE 10-1. SUMMARY OF PERFORMANCE AUDIT PARAMETERS

Parameter	Analytical Method
Cations	
Na^{++}	Atomic Absorption
Ca^{++}	Atomic Absorption and Titrimetric
K^{+}	Atomic Absorption
Mg^{++}	Atomic Absorption
Anions	
Cl^{-}	Ion Chromatography
F^{-}	Ion Chromatography
$SO_4^{=}$	Ion Chromatography
Physical	
Total Hardness	Titrimetric
Alkalinity/Acidity	Titrimetric
pH	Potentiometric
Conductivity	Conductimetric
Total Dissolved Solids	Gravimetric

SECTION 11

PREVENTIVE MAINTENANCE

Radian sampling and analytical equipment is routinely serviced after each field program to restore the equipment to original operating specifications. Prior to a field program all instrumentation are set up and checked for proper operation. At this time any worn or inoperative components are identified and replaced.

In addition to the instrumentation and apparatus required to support on-site measurements and data evaluation, a substantial inventory of spare parts and supplies will be available on-site to minimize down time in the event of breakage and/or failure. Spare parts for the anlaytical instrumentation will include valves, injection ports, tubing, tubing connectors and eluent containers for the ion chromatograph; aspirator capillary and burner head for the atomic absorption spectrometer; filters and cuvets for the spectrophotometer; and two pH meters and electrodes. Additionally, necessary hand tools and trouble shooting devices such as tubing flaring unit for the IC, soldering iron, and digital volt-ohm-ammeter will be available on-site. Also, a large inventory of spare glassware and miscellaneous small items will be supplied in the mobile laboratory.

The lead chemist on site will also maintain a contact in Austin whereby any additional parts, supplies, or replacement instruments needed may be shipped and received in the minimum possible time. Should a major piece of equipment or instrumentation fail and on-site repair not be possible, a replacement may be obtained from Austin in one to two days.

SECTION 12

ASSESSMENT OF PRECISION, ACCURACY, AND COMPLETENESS

The performance audits and QC analyses conducted during the pilot unit testing program are designed to provide a quantitative asessment of the measurement system data. The two aspects of data quality which are of primary concern are precision and accuracy. Accuracy reflects the degree to which the measured value represents the actual or "true" value for a given parameter, and includes elements of both bias and precision. Precision is a measure of the variability associated with the measurement system. The completeness of the data will be evaluated based upon the valid data percentage of the total tests conducted.

Precision of the measurement data will be based upon replicate analyses (replicability) and control sample analyses (repeatability). Variability will be expressed in terms of the coefficient of variation (CV) for the replicate and repeat analyses where,

$$CV = \frac{\text{Standard Deviation}}{\text{Mean}} \times 100\%$$

This term is independent of the error (accuracy) of the analyses and reflects only the degree to which the measurements agree with one another, not the degree to which they agree with the "true" value for the parameter measured. The CV is in units of percent since it is the standard deviation of the mean expressed as percent of the mean (relative standard deviation).

Analytical accuracy will be quantitated based upon the performance audit results. The audit data will be summarized in terms of "relative error", or "%Δ". This reflects the degree to which the measured value agrees with the actual value, in terms of percent of the actual value:

$$\text{Relative Error } (\%\Delta) = \frac{\text{Measured value - Actual value}}{\text{Actual value}} \times 100\%$$

This way of expressing accuracy allows for the comparison of accuracy at different levels (e.g., different concentrations), and for different parameters of the same type (e.g., different compounds analyzed by the same method).

SECTION 13

CORRECTIVE ACTION

Corrective action may be initiated by either the QC coordinator as the result of QC procedure results or the QA coordinator (through the Project Director) as the result of QA audit results. Table 13-1 lists the QC limits for data acceptability and the corrective action required. The corrective action scheme is shown in the form of a flow chart in Figure 13-1

TABLE 13-1 SUMMARY OF QUALITY CONTROL LIMITS AND CORRECTIVE ACTION

Parameter	Method	Control Standard	Control Limit	Corrective Action
Cations	Atomic Absorption	Aqueous Solution (see Table 9-1)	±5%	
Anions	Ion Chromatography	Aqueous Solution (see Table 9-1)	±5%	
Calcium	Titrimetric	Aqueous Solution Ca AA Standards	±5%	
Hardness	Titrimetric	Aqueous Solution Ca and Mg AA standards	±5%	1) Repeat QC analysis
Alkalinity	Titrimetric	Aqueous Na_2CO_3 and $NaHCO_3$	±5%	2) Recalibrate/Restandardize
Silica	Spectrophotometric	Aqueous Solution Si AA standard	±10%	3) Repeat QC analysis
Phosphate, Ortho- and Total	Spectrophotometric	Aqueous KH_2PO_4	±10%	4) Repeat sample analyses
Conductivity	Wheatstone Bridge	Aqueous KCl	±5%	
pH	Potentiometric	Certified Buffer Solutions	Within 0.1 pH unit for buffer 3 units from calibration buffer	
TDS	Gravimetric	Calibrated Weights	±2%	
TSS	Gravimetric	Calibrated Weights	±2%	
Specific Gravity	Gravimetric	DI H_2O at 20°C	±2%	

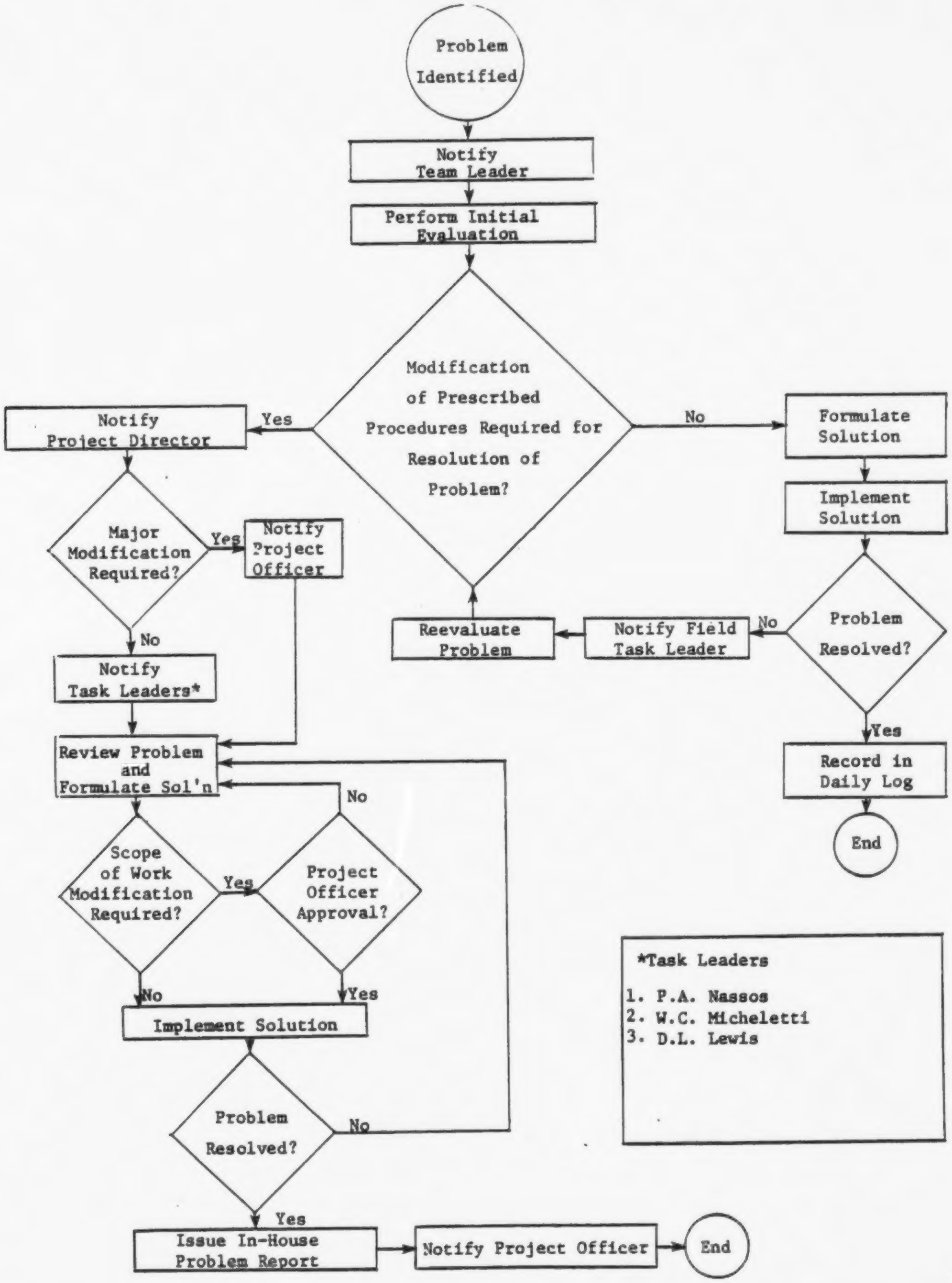

Problem Identified
Notify Team Leader
Perform Initial Evaluation
Modification of Prescribed Procedures Required for Resolution of Problem?
Yes
No
Notify Project Director
Formulate Solution
Implement Solution
Major Modification Required?
Yes
Notify Project Officer
No
Notify Task Leaders*
Problem Resolved?
No
Notify Field Task Leader
Reevaluate Problem
Yes
Record in Daily Log
End
Review Problem and Formulate Sol'n
No
Scope of Work Modification Required?
Yes
Project Officer Approval?
No
Yes
Implement Solution
Problem Resolved?
No
Yes
Issue In-House Problem Report
Notify Project Officer
End
*Task Leaders
1. P.A. Nassos
2. W.C. Micheletti
3. D.L. Lewis

Figure 13-1. Corrective Action Flow Scheme

SECTION 14

QUALITY ASSURANCE REPORTING

The Chemistry Coordinator, Mr. P.A. Nassos, will maintain close contact with the lead chemist on site throughout the duration of the field testing effort. The lead chemist will submit QC data summaries to Mr. Nassos on a biweekly basis. Mr. Nassos will, in turn, provide copies of these data to the QA Coordinator for evaluation. Following the performance audits, the QA Coordinator, Mr. D.L. Lewis, will document the results in a technical memorandum which will be circulated to the Radian Program Manager, Project Director, and Project Task Leaders. Finally, all audit data and QA data will be documented, as appropriate, in the program final report.

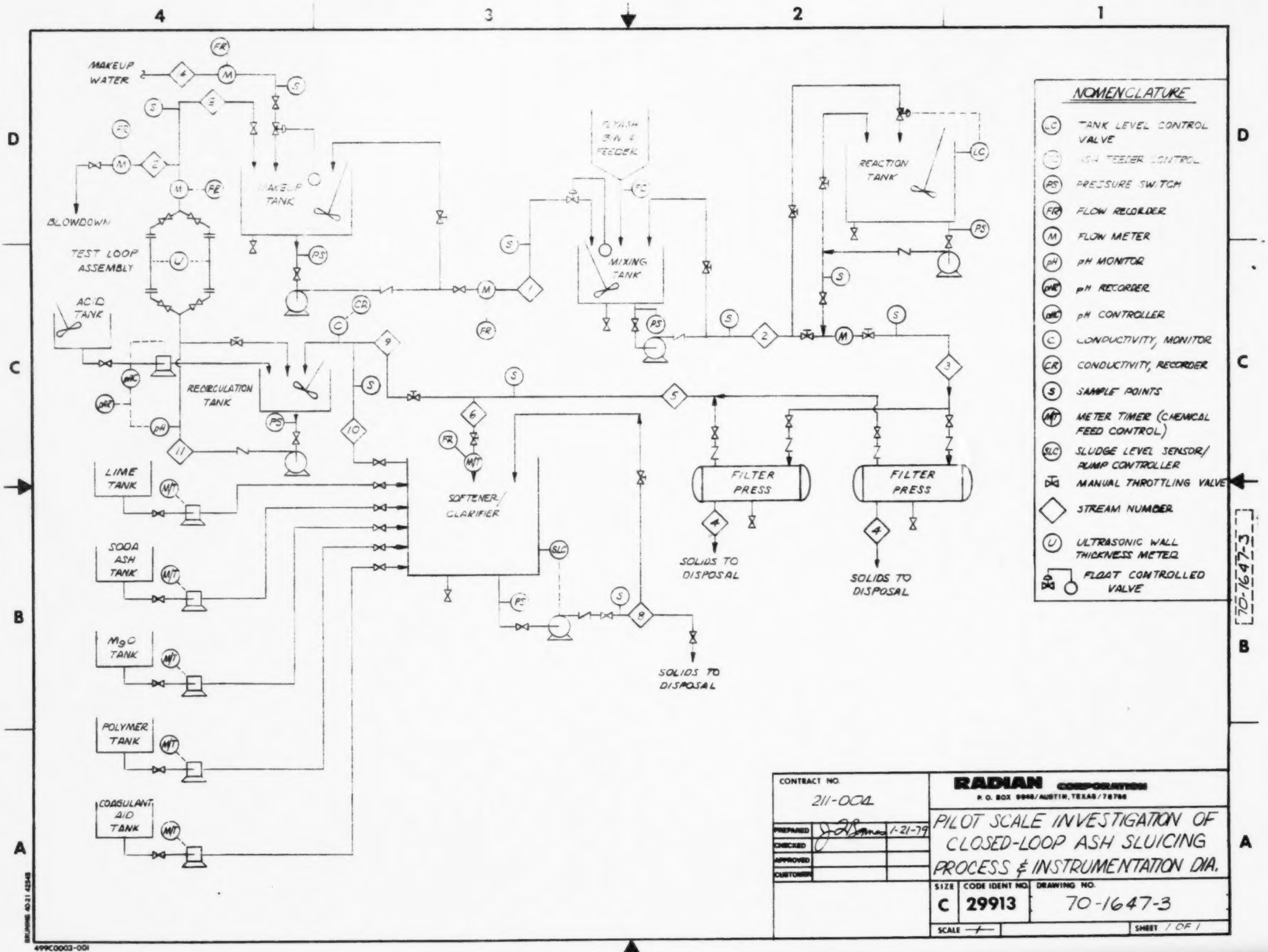
APPENDIX I

OPERATING MANUAL FOR
ASH SLUICE PILOT SYSTEM

OPERATING MANUAL

"PILOT SCALE INVESTIGATION OF CLOSED LOOP ASH SLUICING"

This operating manual is to assist in the initial startup of the ash sluice pilot system in the configuration of flow diagram 70 1647-3. The equipment number refers to Ref-Chem drawing RC-1000. Several other configurations are possible with the system but have not been addressed in these instructions. The emphasis of these instructions has been to provide a basic guideline for a safe and orderly equipment startup/shutdown including equipment response to power failure and automatic shutdown protection. This document is to be used in conjunction with the maintenance manual for this system. Operating instructions in this manual may deviate slightly with procedures recommended by the equipment manufacturer. Where this situation arises, the manufacturer's recommendations should be followed explicitly.


4
3
2
1
D
C
B
A
MAKEUP WATER
BLOWDOWN
TEST LOOP ASSEMBLY
ACID TANK
MAKEUP TANK
RECIRCULATION TANK
FLYASH BIN & FEEDER
MIXING TANK
REACTION TANK
SOFTENER/ CLARIFIER
FILTER PRESS
FILTER PRESS
SOLIDS TO DISPOSAL
SOLIDS TO DISPOSAL
SOLIDS TO DISPOSAL
LIME TANK
SODA ASH TANK
MgO TANK
POLYMER TANK
COAGULANT AID TANK
1
2
3
4
5
6
8
9
10
11
FR
M
S
FE
U
pH
PS
C
CR
SLC
MT
LC
NOMENCLATURE
LC TANK LEVEL CONTROL VALVE
ASH FEEDER CONTROL
PS PRESSURE SWITCH
FR FLOW RECORDER
M FLOW METER
pH pH MONITOR
pHR pH RECORDER
pHC pH CONTROLLER
C CONDUCTIVITY, MONITOR
CR CONDUCTIVITY, RECORDER
S SAMPLE POINTS
MT METER TIMER (CHEMICAL FEED CONTROL)
SLC SLUDGE LEVEL SENSOR/ PUMP CONTROLLER
MANUAL THROTTLING VALVE
STREAM NUMBER
U ULTRASONIC WALL THICKNESS METER
FLOAT CONTROLLED VALVE
70-1647-3

CONTRACT NO.
211-004

PREPARED J. L. Sames 1-21-79
CHECKED
APPROVED
CUSTOMER

RADIAN CORPORATION
P. O. BOX 9948/AUSTIN, TEXAS/78766

PILOT SCALE INVESTIGATION OF
CLOSED-LOOP ASH SLUICING
PROCESS & INSTRUMENTATION DIA.

SIZE C
CODE IDENT NO. 29913
DRAWING NO. 70-1647-3
SCALE —/—
SHEET 1 OF 1

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SAFETY

This manual is designed to be a guide for the safe and orderly startup/shutdown of the ash sluice system including equipment response to a power outage and automatic shutdown protection. This manual is no substitute for COMMON SENSE AND RECOGNITION OF AN UNSAFE OPERATING CONDITION. The SAFETY of operating personnel should be the first and primary consideration during normal operation or emergency conditions. Operators should be aware of the following safety factors at all times:

1. The system uses a combination of 480 volt, 240 volt, 208 volt, 3 phase power, and a 120 volt single phase power, all of which are extremely dangerous! Repairs or modifications should be made by ONLY trained electricians. Caution should be exercised whenever breakers are energized or de-energized. The skids contain a grounding system complete with a grounding rod. THE AREA AROUND THE GROUNDING ROD SHOULD BE KEPT WET AT ALL TIMES.

2. Loose clothing should not be worn around rotating equipment.

3. A hard hat and safety glasses should be worn at all times in the operating area.

4. Protective equipment such as gloves, eye protection, and protective clothing should be worn at all times when handling chemicals.

5. Unsafe conditions should be reported to the lead engineer, IMMEDIATELY!

6. The mounting and interconnection of equipment on transportable skids will require the use of flexible hose and piping on the skid deck and ground. Extreme caution should be exercised to avoid these trip hazards in the operating area.

SYSTEM STARTUP/SHUTDOWN SEQUENCE

The general startup and shutdown sequence will be outlined here for the main process flow system. Auxiliary operators and systems will be discussed later under the individual skid startup/shutdown discussions.

System Startup (All systems energized, ash storage bin full and all systems full of water to the normal operating level)

1. Start makeup tank pump
2. Start ash mixing tank pump
3. Start reaction tank pump (if required)
4. Start recirculation tank pump
5. Start ash storage bin gyrator
6. Start ash feeder

System Shutdown (All systems operating)

1. Stop ash feeder
2. Stop recirculation tank pump
3. Stop reaction tank or ash mixing tank pumps
4. Stop makeup tank pump
5. Stop ash storage bin gyrator

GENERAL OPERATING NOTES

1. The system is designed to maintain a 50 gpm slurry flow rate to the filter press. This must be set by using the manual valve on the clear water outlet of the filter press. If the flow rate varies more than ±5 percent, an alarm horn will sound. The flow rate must then be adjusted to the proper setting.
2. The ash feeder should be the FIRST equipment shutdown. This will avoid overloading the ash mixing tank with ash and a major cleanup disposal problem. The ash feeder will not start unless the ash mix tank pump is running.
3. The recirculation tank pump is the only pump in the system that will start and stop as the recirculation tank level rises and falls. During shutdown it is important that this pump be shut down immediately after the ash feeder to avoid overflowing the makeup tank.

MAKEUP TANK SKID

The makeup tank skid is designed to blend recirculated sluicing water with service water makeup. Blending is accomplished in the makeup tank (T101). Blended water is then transferred to the ash mixing tank by the makeup tank pump (P101). Prior to the blending, the recirculated water passes through a test loop assembly consisting of two test spools. These spools are heat traced and insulated to provide a warm tube surface to enhanced scale formation. The soda ash feed tank (ST602) and pump (MT602) are also located on this skid but are not operated in conjunction with the other equipment on the skid.

Operating Instructions

Initial Startup

1. Check all pump and agitator start/stop switches to be sure they are in the STOP position.
2. Energize the 480 volt and 120 volt power supply breakers in the control building for pump (P101) and agitator (MX101) and soda ash chemical feed system (MT603) for both pump and agitator. Energize 120 volt breaker for flow meters 101, 102, and 105.
3. Read and record all flow meter readings.
4. Close the manual blowdown valve downstream of meter 102.
5. Open isolation valves up and downstream of one of the test spools in the test loop assembly and valve on recirculation line entering makeup tank.
6. Open manual valve on service water (makeup water) and begin filling makeup tank.
7. Adjust makeup tank level float valve to maintain the water level between 6 to 8 inches from the top of the tank.
8. Start makeup tank agitator when tank is full.

9. Open pump suction valve on makeup tank pump (P101), close pump discharge valve, and open (2 turns) pump recirculation line valve back to makeup tank. Start pump and allow pump to recirculate in this mode for only 5-10 minutes (maximum). Open the discharge valve when the ash mixing tank is ready for service. When ash mixing tank is in service use recirculation to adjust the flow rate through meter 104 on ash mixing tank skid.

10. When required open manual blowdown valve to set system blowdown flow rate on meter 102.

Normal Shutdown

1. Normal shutdown will involve sequential shutdown of makeup tank pump and agitator.

2. The recirculating tank pump (P111) on the softener skid should be shut down to avoid overflowing the makeup tank.

Automatic Shutdowns

1. The makeup tank pump (P101) is designed to shut down at a preset low water level in order to protect the pump from operating dry. The pump will not restart until the water level is again above this point. DO NOT TRY TO RESTART THE PUMP UNTIL THIS CONDITION IS REMEDIED! If the tank agitator impeller is not submerged, the agitator should be SHUTDOWN IMMEDIATELY! This will avoid potential vibration damage.

ASH MIXING SKID

The ash mixing skid is designed to blend fly ash with blended water from the makeup tank skid in slurries ranging from 1 to 10 weight percent solids. The skid consists of a fly ash storage bin (FB201) and feeder, a mixing tank (T201), and a baghouse filter and blower (BF201).

Loading Ash Storage Bin

Loading will be accomplished differently at Plant Bowen and the Scholz Plant. At Plant Bowen the following procedure will be used:

1. Close slide gate valve between ash storage bin and ash feeder if feeder is not in service. With the feeder in service, the gate valve should be completely open.
2. Insure proper connection with the Monier ash truck has been made and all valves are open. Have the Monier truck operator start the unloading blower on the truck.
3. Start the baghouse filter blower at this time and the air supply to the baghouse should be turned on.
4. When the truck is empty, shut down the blower and disconnect hoses.

At Plant Scholz the ash loading operation will be closely interfaced with the plant operation. Ash will be drawn from the plant ash conveying line. The following procedure should be used when the plant is removing ash from the precipitator hoppers.

1. Close slide gate valve between ash storage bin and ash feeder if the feeder is not in service. With the feeder in service, the slide gate should be completely open.
2. Open ash bin inlet valve.
3. Start air supply to the baghouse filter.

4. Start baghouse filter blower.

5. When plant stops transporting ash or ash storage bin is full, close inlet bin valve.

During 10 weight percent slurry testing a high percentage of the ash produced by the plant will be used by the pilot system.

Note: An accurate inventory of ash moving through the system must be maintained in order to determine when a full truckload of ash is required. The storage bin has a 750 ft^3 capacity which will hold approximately 25 tons of ash. Ash must be supplied in full truck load quantities.

Operating Instructions

Initial Startup

1. Check the mix tank agitator (MX201), ash feeder, baghouse blower (BF201), mix tank pump (P201), and storage bin gyrator (FB201) START/STOP switches on reaction tank skid to be sure they are in the STOP position.

2. Energize 480 volt power supply breakers in the control building for the agitator (MX201), ash feeder (FB201), and the baghouse blower (BF201). The ash mix tank pump (P201) is on the reaction tank skid and should be energized at this time also.

3. Open manual valve on the inlet to tank T201 and with makeup tank pump (P201) running begin filling the ash mixing tank.

4. Adjust ash mixing tank level control float valve to maintain water level between 6-8 inches from the top of the tank.

5. When the tank is full, start the agitator.

6. Open suction on mix tank pump (P201), close pump discharge valve, and open pump recirculation line valve (2 turns) back to mix tank. IF RECIRCULATION VALVE IS OPENED TOO FAR, THE PUMP WILL OVERLOAD! Start pump and allow pump to recirculate for 5-10 minutes (maximum). Open the pump discharge valve when the reaction tank or filter press is ready for service.

7. Start ash storage bin gyrator.

8. Set feeder ash flow rate as per Vibra Screw instructions.

9. Start ash feeder (see automatic shutdown).

NOTE: Ash feeder should be the last system to be started at the beginning of a test run. The flow configuration should be set with the system completely full of water and with all appropriate pumps operating full of water and with all appropriate pumps operating before the ash feeder is started. If problems are encountered with any part of the system, the ash feed system should be the FIRST subsystem shutdown.

Normal Shutdown

1. Normal shutdown will involve sequential shutdown of ash feeder, mixing tank pump, and agitator. If the tank is to be kept full during the outage, the agitator should be left on.

2. Appropriate valves should be closed to avoid backflow or loss of water from the system.

Automatic Shutdown

1. The ash mixing tank pump is designed to shut down at a preset low water level in order to protect the pump from operating dry. The pump will not restart until the water level is again above this point. DO NOT TRY TO RESTART THE PUMP UNTIL THIS CONDITION IS REMEDIED! If the tank agitator impeller is not submerged, the agitator should be SHUT DOWN IMMEDIATELY! This will avoid potential vibration damage.

2. The ash feeder is interlocked with the ash mix tank pump and will not start unless the pump is running. If the pump shuts down on low level, the ash feeder will automatically shutdown.

3. If power to the skid is lost, the ash mixing tank pump and and feeder will not restart when power is restored. The pump must be manually restarted first and then the feeder must be manually restarted. The baghouse blower and the ash storage bin gyrator will automatically restart when power is restored. All moving equipment should be switched to stop during a power outage.

REACTION TANK SKID

The reaction tank skid is designed to allow additional ash slurry residence time (reaction time). The skid consists of the reaction tank (T301), reaction tank pump (P301) and agitator (MX301), ash mixing tank pump (P201), and the air compressor (ARC 401).

Operating Instructions (Reaction tank in service)

1. Check all pump and agitator start/stop switches to be sure they are in the STOP position.
2. Energize the 480 volt breakers in the control buildings for pump (P301), pump (P201), and agitator (MX301), and 120 volt power supply for flowmeter (M106).
3. Read and record flowmeter reading.
4. When reaction tank is to be used, open tank inlet valve. When the reaction tank is not to be used, the reaction tank inlet valve should be closed, the bypass valves opened, and the discharge valve from pump (P301) should be closed.
5. With pump (P201) running, fill the reaction tank (T301), and set the level controller to maintain a water level 6-8 inches from the top of the tank. Setting the level control will require adjustment of the set point control mounted on the side of the tank. The reaction tank level can be adjusted upward or downward to control the residence time in the tank.
6. Start reaction tank agitator (MX301) when tank is full.
7. Open suction valve on reaction tank pump (P301), close pump discharge valve, and open pump recirculation line valve (2 turns). IF RECIRCULATION VALVE IS OPENED TOO FAR, THE PUMP WILL OVERLOAD! Start pump and allow pump to recirculate for 5-10 minutes (maximum). Open the pump discharge valve when the filter press is ready for service.

Normal Shutdown

1. Normal shutdown will involve sequential shutdown of the reaction tank pump and agitator. If tanks are to be kept full during shutdown, the agitator should be left on.

2. Appropriate valves should be closed to avoid backflow or loss of water from the system.

Automatic Shutdown

1. The reaction tank pump (P301) is designed to shut down at a preset low water level in order to protect the pump from operating dry. The pump will not restart until the water level is again above this point. DO NOT TRY TO RESTART THE PUMP UNTIL THIS CONDITION IS REMEDIED! If the tank agitator impeller is not submerged the agitator should be SHUTDOWN IMMEDIATELY! This will avoid potential vibration damage.

2. If power to the skid is lost, the pumps and agitators will restart automatically if the START/STOP switches are not left in the STOP position. All moving equipment should be switched to STOP during a power outage.

FILTER PRESS SKIDS

The filter press skids are designed to remove the ash from the slurry. The skids consist of two filter presses (FR401, FR402), a recirculation pump (P111), and the sludge pump (P601). The recirculation pump is used in conjunction with the recirculation tank on the softener skid. The sludge pump is used during the filter press slurry dump cycle.

Operating Instructions

Initial Startup

1. Check all pump START/STOP switches to be sure they are in the STOP position (including filter press hydraulic power packs pump).
2. Energize 480 volt power supply breakers in the control building for all pumps (P111, P601) and the hydraulic power pack.
3. Open the inlet valve and outlet valve of filter press selected for service.
4. Close sludge pump suction valve and drain valve.
5. Open vent valve on top of filter press and fill the filter press until water flows from the vent. (Fill using the reaction tank pump, ash mixing tank pump, or service water line.)
6. Slowly close the vent valve and establish flow to the recirculation tank. CAUTION - OPENING AND CLOSING VALVES QUICKLY MAY RESULT IN WATER HAMMER AND MAY BURST THE FILTER PRESS RUPTURE DISC. Filter press rapture disc is rated at 70 psi.
7. The flow rate from the reaction tank or ash mixing tank pumps should be adjusted using the filter press outlet valve.

Sludge Dump Cycle

1. Place standby filter press in service as per instructions above.
2. Slowly close inlet and outlet valves of the filter press to be cleaned.

3. Slowly open vent valve and relieve the pressure on the vessel.

4. Open sludge pump suction valve.

5. Start sludge pump and pump filter press contents back to ahs mixing or reaction tank.

NOTE: ONLY clear water should be returned to the system. If water contains a high ash content pumping should be switched to the drain. Sludge pump will empty filter vessel in 5-8 minutes. DO NOT RUN PUMP COMPLETELY DRY! This must be watched closely.

6. Connect service water hose to the filter press flushing valve and refill vessel with service water.

7. Connect sludge pump discharge line and partially open pump discharge valve. CAUTION: DO NOT OPEN THE DISCHARGE VALVE COMPLETELY OR PUMP WILL OVERLOAD.

8. Turn on air supply to filter press vibrator.

9. Start the sludge pump and filter plate vibrator.

10. Allow the sludge pump to evacuate the vessel several times or until a clear water stream. DO NOT RUN THE SLUDGE PUMP DRY! On successive drain and fills the pump may require shutdown during the fill cycle.

11. When filter is clean, pump filter down with sludge pump. Shut down sludge pump and drain residual water from the filter press using the drain valve.

12. Close the sludge pump suction and drain valve.

13. The filter is now ready to return to service as outlined before.

Normal Shutdown

1. Normal shutdown of the system will require the shutdown of the ash mixing or reaction tank pump.

2. If the filter press is to be idle for more than a few hours the sludge dump cycle should be initiated. The filter press should be left drained when not in use.

Automatic Shutdown

1. Only the recirculation pump (P111) on this skid will shut down automatically on low water level. This is discussed in the softener skids automatic shutdown section.

2. If power to the skid is lost, the sludge pump and recirculation pump will automatically restart if the START/STOP switches are not left in the STOP position. All moving equipment should be switched to STOP during a power outage.

SOFTENER SKID

The softener skid has been designed to provide two treatment options; sidestream softening and pH control. The skid consists of four chemical feeds systems, a softener (SC601), and the recirculation tank (RT111). The chemical feed systems include acid (T111), lime (LT601), magnesium oxide (MT603), and polymer (PT604). An additional soda ash chemical feed system (ST602) is located on the makeup tank skid. Each chemical feed system consists of a tank, an agitator, and a feed pump.

Operating Instructions

Initial Startup

1. Check all pump, agitator, and softener paddle mixer to be sure that start/stop switches are in the STOP position.
2. Energize the 480 volt power supply breaker to the softener paddle mixer. Energize the 120 volt power supply breaker to the chemical feed systems, the pH controller, conductivity monitor, and the softener inlet flowmeter.

Normal Operation with pH Control System

1. After all systems have been energized and with ash mixing tank pump or reaction tank pump running open manual inlet valve to the recirculation tank and fill tank to a water level 6-8 inches below the top of the tank. Close the tank inlet valve.
2. When tank is full start, start agitator (MX111).
3. Open pump suction valve on recirculation tank pump (P111). Close the recirculation pump discharge valve and open recirculation line valve (2 turns). Start pump and allow to recirculate back to the recirculation tank until the makeup tank (T101) is in service. This recirculation time period should not exceed 10 minutes. When the makeup tank is ready, slowly open the discharge valve and adjust the recirculation valve.
4. The recirculation tank pump is designed to turn on and off as the water level drops below a preset point. THIS IS THE ONLY PUMP IN THE SYSTEM THAT IS DESIGNED TO MODULATE WITH TANK LEVEL. THIS PUMP MUST BE TURNED OFF BEFORE THE MAKEUP TANK PUMP IN ORDER TO AVOID OVERFLOWING THE MAKEUP TANK.

4. Using the service water hose, fill to the 50 gallon water level in the acid feed tank and turn on agitator. The acid feed system is designed to inject a 10 weight percent sulfuric acid to control the system pH. In order to mix a 10 percent solution SLOWLY and CAREFULLY ADD 3 gallons of 93 weight percent (66° Baume) sulfuric acid. DO NOT MIX ACID CONCENTRATIONS GREATER THAN 10 PERCENT! If higher concentrations are mixed, the temperature rise of the mixture may exceed the maximum operating temperature of the polypropylene tank (∿180°F). Acid addition rates (10 wt%) range from 2 to 15 gallons per hour. When flow rates are low a 3 weight percent solution may be mixed in order to minimize acid handling. The acid tank should remain covered at all times when acid is not being added. WARNING - EXTREME CAUTION MUST BE USED WHEN FEEDING ACID BECAUSE OF THE LIMITED ACCESS THE CHEMICAL FEED TANK AREA.

NOTE: The acid feed system can be used to feed caustic soda also. THE SYSTEM MUST BE THOROUGHLY CLEANED AND FLUSHED BEFORE ADDING CAUSTIC TO THE SYSTEM OR VICE VERSA. A maximum of caustic concentration of 5 weight percent or 20 pounds of dry caustic per 50 gallons of water should be used. DRY CAUSTIC SHOULD BE HANDLED CAREFULLY, ESPECIALLY UNDER WINDY CONDITIONS!

5. The acid feed pump is controlled by the pH controller. The pump will cycle on and off as required to maintain a constant pH in the recirculation tank effluent.

Normal Operation with the Softener

1. The lime, soda ash, polymer, and magnesium oxide tanks should be premixed according to the requirements of the inlet water chemistry. The dosages must be determined by bench tests. The mixing procedure will be outlined in the field. However, the following maximum concentrations should not be exceeded.

   Lime - 5 wt%
   Soda Ash - 5 wt%
   Coagulant - 10 wt% (alum)

   Polymer should be mixed in very dilute solution to avoid high viscosity.

2. The recirculation tank should be started in the same manner as previously described.

3. Close the inlet valve to the recirculation tank and open the valve to the softener inlet.

4. Start the chemical feed pumps.

5. With the ash mixing tank pump or reaction tank pump running, fill the softener.

6. When the softener is approximately 25 percent full, start the paddle mixer.

7. When the softener is full, set the blowoff and flushback timers. The duration of blowoff must be calculated from the inlet chemistry and the expected sludge production rate. BLOWOFF SHOULD BE KEPT TO A MINIMUM TO AVOID EXCESSIVE WATER LOSS FROM THE SYSTEM!

Normal Shutdown

1. Shutdown should proceed in the following sequence: close inlet valve to softener, stop recirculation pump and agitator, stop chemical feed pumps and agitators.

2. If shutdown is to be for an extended time period, the chemical feed systems should be drained and flushed. The softener inlet feed line should also be flushed. All sludge should be removed from the softener, the softener drained during periods when not in use.

Automatic Shutdown

1. The recirculation pump (P111) will shut down at a preset low water level in order to protect the pump from running dry. The pump will not restart until the water level is again above this point. THIS PUMP WILL AUTOMATICALLY RESTART ITSELF WHEN THE WATER LEVEL IN THE TANK REACHES A PRESET HEIGHT. If the tank agitator impeller is not submerged, the agitator should be SHUT DOWN IMMEDIATELY! This will avoid potential vibration damage.

2. The chemical feed pumps and agitators and the softener paddle mixer will NOT shut down if a low liquid level is experienced. These tanks must be checked frequently during use in order to avoid pump damage.

3. If power to the skid is lost, all pumps, agitators, and the paddle mixer will restort automatically if the START/STOP switches are not left in the STOP position. All moving equipment should be switched to STOP during a power outage.